INTRODUCTION
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Temperature is one of the most important environmental factors with tremendous influence on the Ecophysiology of organism. Results of many studies are available in the literature on various fish-temperature relationships. Fish can perceive water temperature changes, which are smaller than 0.1°C and every fish species has its characteristic acclimatization temperature and temperature tolerance limit, which might change seasonally in a given stock and can be slightly different from one stock to the other of the same species (Laevastu and Murray, 1981).

Fishes are found to be inhabitants of environmental temperatures ranging from below 0°C to 50°C. The Antarctic shallow water fish, *Notothemiacoriceps*, can survive at sub-zero temperature of -2.09°C (Hargens, 1971), whereas *Cyprinodon macularius* can tolerate a higher temperature of 52°C (Nikolsky, 1963) and perhaps these are the lowest and highest environmental temperatures respectively at which inhabitation of fishes has been reported so far.

The rate of metabolic process in the form of activity of animals is influenced by the ambient temperature. This environmental factor exerts a tremendous influence on the ecophysiology of animal, its activity of distribution (Precht et al., 1973). The distribution of animals has been extending from more uniform temperature conditions of land and waters within the tropics, towards the poles into areas
of extreme climatic conditions (Phol, 1976). An organism is an inseperable part of its environment. Hence, it forms the part and parcel of the environment. Environment being labile, no organism lives under constant environmental conditions. The environmental lability imposes considerable stress upon the inhabiting organisms which in turn have to adjust or adapt to it in order to survive in the extreme environments. If they fail to adapt, organisms succumb to the imposed environmental stress. And so, the animal has to adapt to the environment in order to survive. Fishes are obligate poikilotherms, some of which can perceive temperature changes of less than 0.5°C (Murray, 1971). Although there is some thermo-regulation by local conservation of muscular heat in at least two groups, the tunas and the lamnid sharks (Fry and Hochachka, 1970, Stevens and Neil, 1978), Most of the fishes lack a mechanism to maintain an independent body temperature and the term thermal conformers is invariably applicable to them. Further, temperature and salinity changes in the environment are always challenges to aquatic poikilosmotic animals and their effects are not predictable, since temperature can modify the effects of salinity and salinity can alter the effects of temperature (Kinne, 1964 a, b). Thus combined effects of salinity and temperature play an important role in the survival dimensions of the animals (Prakasam and Azariah, 1990).
The adaptation to a new temperature or a change in temperature involves a number of active processes and hence energy expenditure is needed for metabolic re-organisation (Hochachka, 1961 a,b, 1967, 1969; Hochachka and Somero 1968, 1969). The compensation to a change in the temperature in poikilotherms is ultimately exhibited at the individual level, cellular level and sub-cellular level involving the enzyme systems. Further, the concept of poikilotherms regulating their metabolism and activity against ambient temperature variations, though in a limited sense, has also been established. Extensive work has been done and voluminous data are available in these areas of thermal adaptation in poikilotherms, especially in fishes (Reviews: Kinne, 1964 ab, Fry, 1964, 1970; Prosser, 1965; papathirao, 1976 b, Precht et al., 1973; Hazel and prosser, 1974; Bashamohideen, 1979, 1983, 1986; Maushtaq Ahmed, 1988, Abdul Rahi, 1989, Shanker Naik, 1993, Heeranaik, 1994). In recent times it has also been known that the similar type of cellular metabolic processes are operated in both poikilotherms and homeotherms (Anthony and Munro, 1964; Hochaka, 1969; Tarr, 1969). This is the outcome of several decades of intensive research in the field of temperature-adaptation in cold blooded animals.

The Phenomenon of stress:

The concept of biological stress has stimulated numerous formal definitions in the scientific literature, the
variety of which bears testimony to the difficulty of establishing a single, comprehensive definition. All the definitions of stress, however, share the common precise of a stimulus action on a biological system and the subsequent reaction of the system. It could be a stimulus or response of the system, and a condition that forces a deviation from homeostasis. The concept of stress in relation to biological systems has evoked a lot of discussion and disagreement. Pickering, (1981) used the term 'stimulus' for stress and the reaction of the system as the 'stress response'. The term stress is used inconsistently. However, the following literature reveals the definition of stress and other terms that come under stress and biological investigations on stress.

The term 'stress' used by Selye, (1950) for the "sum of all the physiological and biochemical responses by which an animal tries to maintain or re-establish a normal metabolism in the face of a physical or chemical force". It is sometimes taken to mean the environmental alteration itself and sometimes the response of fish, population or ecosystem (Pickering 1981). According to Esch and Hazen, (1978), stress is the effect of any environmental alterations or forces that extend to homeostatic or stabilizing processes beyond their normal limits at any level of biological organisations. "Stress" is used to mean the environmental factor itself and a stress factor or "Stressor" is an
environmental change that is severe enough to require a physiological response on the part of the animal. If the stress response can re-establish a satisfactory relationship between the changed environment and the fish population or ecosystem adaptation to the stress will occur. However, because of species shifts and energy drains which may occur, the original conditions may never be restored (Wedemeyer and Mc Leay, 1981).

**Thermal Stress:**

"Thermal Stress" can be defined as any temperature change that produces a significant disturbance in the normal functions of a fresh water teleost and thus decrease the porbability of survival (Elliot, 1981). This definition is similar to that proposed by Brett (1958) and assumes that the response is a stochastic variable that can be measured quantitatively. Several authors used different terminology in studies regarding tolerance and resistance to thermal stress. Richards et al., (1977) in their review "Temperature preference -studies in environmental impact assessment 'defined "Preferred" or "selected" temperature as the temperature at which fishes are most frequently found when they are allowed to move freely in a temperature gradient. The critical temperature ranges are the ranges over which a significant disturbance in the normal behaviour of fishes may occur ie., there may be obvious sign of thermal stress. As most of the work on thermal stress has been to predict the

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effects of thermal discharge on fish, information on the upper critical range is more numerous than on the lower critical range. The lowest value in the upper critical range is close to the "avoidance", "restlessness" or "disturbing" temperature (coutant, 1977: Alabaster and Lloyd, 1980), whilst the highest value is the maximum temperature (Critical thermal maximum) at which fishes survive for brief periods. The critical thermal maximum is the temperature at which fish loses its ability to escape from the lethal conditions.

The stress responses of teleostean fishes are considered to be similar in nature to the General Adaptation Syndromes (GAS) proposed for mammalian vertebrates (Selye, 1973). Implicit in this concept is the probability that the health or well-being of fish may be impaired by stress momentarily. One might thus alternately view stress not directly in physiological terms but rather functionally as defined by Brett (1958). The physiological responses to a variety of stress have been outlined for fishes by Gronow (1974 a,b), Maxeaud et al., (1977), Eddy (1981) and Hughes (1981). Stress has been described as (a) an alarm reaction, in which stress hormones are released (b) a stage of resistance during which adaptation occurs and (c) a stage of exhaustion if adaptation is lost because the stress was too severe or long lasting. These three phases can not be differentiated exactly in all cases. Therefore, many authors refer only to stress effects comprising all symptoms exhibited
under physiological load. Further, it is widely accepted that the stress response as a whole is characterized by physiological changes, which tend to be similar for stressors as varied as handling, disease treatment, fright, forced swimming, anesthesia, rapid temperature change or scale loss. Stress response of a fish is analogous in many ways to that occurring in the higher vertebrates (Peters, 1979). The response of a fish to stress is either primary or secondary. Primary responses include neuro-endocrine and endocrine reactions (Donaldson, 1981; Mazeaud and Mazeaud, 1981) and the secondary responses to thermal stress which include disturbances in osmotic and ionic regulations, metabolit processes, growth, reproduction and behaviour. The ultimate response is death (Elliot, 1981). The reactions of a fish to changes in temperature are multiple in number and complex in nature, because homeostasis with respect to temperature appears to be more critical responses or compensatory acclimations (Prosser, 1965). A terminology on stress in detail is available in the book stress and Fish, (Pickering, 1981). However "stress" is being defined in recent times as physiological load acting upon an animal or man and the factors causing stress are called as "Stressors" (Kunnemann & Precht, 1975); Brune and Gronow, 1975 a,b, Grigo 1975; Bashamohideen and Kunnemann 1979; Bashamohideen 1984, 1989).
The Process of adaptation:

The adaptation is a slow process in which the fish adjust to a slow change in the environment without physiological load on the part of it. Adaptation is the variation that permits biochemical or other activities within a normal or middle range of environmental factors. Metabolic compensations are particularly well known in acclimation to temperatures. A function may show complete or partial compensation or even over compensation as a result of acclimation. Resistance and capacity adaptations may or may not be related in mechanism, both may be meaningful or one may be paradoxical (Precht, 1958). Further many poikilothermic animals especially fishes respond to changes in environmental temperature with alternations in metabolic rate (capacity adaptation) and with variations in tolerance to environmental extreme temperatures-cold or hot (resistance adaptation). The former enables animals to become independent of the ambient temperature and the latter is advantageous to survive in extreme temperatures.

Capacity adaptation is usually measured as the rate of some activity mostly in term of metabolic rate. Developmental rates of cold water animals are faster than those of warm water species at a given temperature. Similar differences are for metabolic rates for some species of fish but not for others and apparently occur rarely in insects. In cold acclimation, a rate temperature curve may be
translated to the left so that at an intermediate temperature the rate for cold-acclimated individuals is higher than for warm-acclimated ones, or a rate temperature curve may be rotated so that the temperature co-efficients are different according to acclimation (Prosser and Nagai, 1968; Prosser, 1973).

It has been discovered that the stress-adaptation results in a gain of response in relation to extremely low and high temperatures ie., in the process of resistance adaptation (Selye, 1950). The process of resistance-adaptation has been reported in the fish, *Rhodeus amarus* as a good example (Kunnemann, 1973) where, the heat resistance of the fish was determined by the increase in the ambient temperature (1°C/minute), beginning from the adaptation temperature like 10°C and 20°C until cessation of opercular movements. These movements can be regarded as an adequate indicator for heat-resistance (Thiede, 1965). In contrast to resistance adaptation, hardening appears to be (shock or stronger stress), adaptation which is effected especially be extreme temperatures and hardening also represents a fast adaptation to abrupt changes in temperatures (especially at sub-lethal temperatures, which act as stressors). In contrast to hardening (shock or stronger stress), resistance adaptation, however, usually requires several days or even longer period. It represents a long-term adaptation to long-lasting climatic changes (Kunnemann and Precht, 1975).
Therefore, when the animals are transferred abruptly to extreme temperatures, either cold or hot, stress results in the form of cold shocks and heat shocks. Therefore, it is also necessary to separate the temperature resistance adaptation from greater stress phenomena, in the form of cold shocks or heat shocks.

When a poikilotherm is subjected to a relatively long term, persistent thermal stress, adaptive changes are initiated that allow organism to exhibit similar rates of physiological activity inspite of widely different body temperatures. Such compensations occur within the life span of an individual of the species and generally requires several weeks for completion, this process is customarily referred to as acclimatization ;if the organism is responding to seasonal fluctuations in the environmental parameters within its natural ecosystems, or acclimation if the organism is responding to a single, well defined environmental parameter under a laboratory situation.

Physiological compensations associated with a period of acclimation or acclimatization are common among poikilotherms and have been reported for all levels of biological organisations.

Thus, many poikilothermic animals respond to changes in the environmental temperature by altering the metabolic rate within the normal range of temperature. Recently, it has been discovered that "temperature-stress" is
entirely different from "temperature-adaptation" (Laudien and Phol, 1975; Kunnemann and Bashamohideen, 1976; Bashamohideen and Kunnemann 1979; Bashamohiddin 1984; Mustaq Ahamed, 1988 and abdul Rahim, 1989). An abrupt temperature change results in the process of stress condition. 'stress' is a physiological load acting upon an animal or man, and the factors which induce stress are called the 'stressors'. Conversely, when the animals are exposed very slowly to a new temperature, they compensate, resulting in the process of adaptation without physiological load on the part of the animal (Bashamohideen, 1979, 1984; Bashamohideen and Kunnemann, 1979). Physiological load means an undue burden on the animal with rapid of steady release of energy (Brett. 1958), Fry (1957, 1964) classified environmental effects into five groups of factors viz., Lethal, controlling, limiting, masking and directive. This approach was followed by Brett (1958) who divided stresses on fish into four categories: lethal (self-explanatory), limiting (restriction in the supply of essential metabolites or interference with the chain of energy release), inhibiting (reduction in the ability of the fish to carry out its normal functions and hence a reduction in its probability survival) and loading (an induced burden on the fish with a rapid or steady release of energy), Limiting inhibiting and loading stress may also be lethal when they continue over longer periods.
Thanks to the pioneering works of Precht and his collaborators of the new approach on adaptation process and the year 1975 heralded the beginning of a new era of approach of differentiation of these thermal-stress phenomena from thermal adaptation processes where, it is possible and necessary to distinguish the two different processes of 'stress' and 'adaptation'. When poikilothermic animals are subjected to thermal changes and when the process of aclimation is complete, one has to differentiate between possible thermal-stress and thermal-adaptation" (Kunnemann and Precht, 1975; Kunneman and Bashamohideen, 1976; Bashamohideen and Kunnemann, 1979 Bashamohideen, 1979, 1982, 1983, 1984, 1985, 1986, 1987 a,b,c, and 1989). Based upon the above factors, in the present investigation, the author has made a humble attempt to differentiate the adaptation process from the stress phenomena and their effects on the fish in recovering from the physiological load that is caused by the stress conditions, towards heat as well as towards cold and ultimately to decipher the mechanisms especially the energetics involved during temperature - stress and temperature - adaptation processes, using the following physiological parameters.

Time Course of Thermal Adaptation:

Many eurythermal poikilotherms are able to survive and function at wide different habitat temperatures. This is largely related to the fact that when a poikilotherm is
transferred from one thermal environment to another, many aspects of its physiology and biochemistry are altered in a manner that often compensates the temperature change. Such compensations to temperature may occur over at least three distinct time course periods. 1) Temperature compensation appears to be instantaneous, 2) compensation is evident in an individual of a species only after a period of acclimation and 3) thermal compensations may become evident over evolutionary time spans (Somero, 1969; Hochachka and Somero, 1973). Physiological responses to the imposed environmental stress may be thermal, osmotic or any other factor may be divided into two categories. 1) immediate or short term responses when the animal is transferred immediately to the stress medium and 2) stabilised or long term responses when exposed to prolonged period in the stress medium. This prolonged period may be hours, days or weeks, or even evolutionary span in different cases of animals (Grainger, 1958, 1960, 1964, a,b, 1966, 1967, 1971; Parvatheswararao, 1968 a, Somero 1969; Somero ; and Hochachka, 1969 Hochachka and Somero, 1973; Hazel and Prosser, 1974; Bashamohideen and Parvatheswararao, 1976; Bashamohideen and Kunnemann, 1979; Bashamohideen, 1982, 1984, 1987 a,b,c).

Thus, when a poikilotherm is adapted to a new thermal regime over a period of time which varies from animal to animal, its metabolic rate after a period gradually undergoes fluctuations and stabilizes at a new rate, which is
maintained during its subsequent sojourn in the new thermal regime, and the attainment of such stabilized rate is said to signal the completion of adaptation (Kinne, 1964 a,b). However, a relationship exists between the stabilical rate in the new thermal regime and the original normal rate in the natural habitat. Temperature differs between different poikilotherms depending upon the differences amongst them in the degree and the direction of metabolic thermal stress.

In several fishes, it was well established that adaptation to higher temperature proceeds faster than adaptation to lower temperature. Studies of this nature on time course of adaptation to thermal stress in tropical fishes has so far received very little attention. Hence, a study of time course of metabolic adaptation to cold and warm temperature is tackled in this investigation and such studies form a good thermal background for further studies of temperature differentiation of thermal-stress from thermal-adaptation.

In most of the fishes, it was reported that adaptation to higher temperatures proceeds faster than at the lower temperatures. This reflects in fishes that increase in heat resistance through warm adaptation is faster than the loss of it or gain in cold resistance through cold adaptation (Spoor, 1955; Brett, 1956) but also the operation of different mechanisms during adaptation to cold and warm
temperatures (Konishi and Hickmann, 1964; Vernberg and Vernberg, 1966 a; Parvatheswararao, 1967, 1968 a,b; Bashamohideen and Kunnemann 1979).

Studies on time course of adaptation to temperature stress in tropical fishes has so far received little attention, despite its importance in the understanding of molecular changes, triggered by the imposed temperature stress (Hzel, 1972). When a Poikilothermic animal is transferred to a new ambient temperature, its metabolic rate shoots up initially, but after a prolonged time stabilises at a new rate and the attainment of such stabilised rate is an indicator for the completion of adaptation (Kinne, 1964 a,b; Parvatheswararao, 1968 a, 1970; Bashamohideen and Parvatheswararao, 1976). Precht (1958) considered and classified these studies involving the attainment of the new stabilised metabolic rate in the new thermal environment into five distinct thermal acclimation patterns in poikilotherms.

Temperature Adaptation-Oxygen Consumption of the whole fish:

Measurements in oxygen consumption have been employed more than any other experimental parameter to monitor changes in metabolism associated with temperature adaptation. The uptake of oxygen rate is considered as a good index for overall physiological activity and an indicator of environmental stress of the animal, and such a physiological index is easy to obtain both in the field and
in the laboratory with a variety of environmental stress, including the temperature-stress of the present investigation. Further, the variation in oxygen consumption can be accounted for the excellent modulation in the metabolic status of the animal (Natarajan, 1980; Bashamohideen, 1984). When the fish is abruptly transferred from a warm to a cold environment, Oxygen consumption drops immediately due to direct kinetic effect of temperature on the reactions involved. After a stabilised phase, which may be several hours or days in duration, the oxygen consumption rises and eventually stabilises at a value characteristic of the cold-adapted state. These fluctuations result due to the operation of stress phenomena (Sidell et al., 1973). Due to the effect of temperature on the oxygen, Solubility, an aquatic poikilotherm exposed to elevated temperature is confronted with a much increased oxygen demand in an environment that is relatively hypoxic (Hazel and Prosser, 1974).

The rate of metabolism of the animal is considered to be a good indicator of thermal stress in animals, and measurement of oxygen consumption has been employed more extensively than any other metabolic parameter. The studies on metabolic adaptation to temperature, indicate that when poikilotherm is adapted to new thermal range over a period of time, which varies from animal to animal, its metabolic rate, after a period gradually diminishing fluctuations, stabilises
at a new rate, which is maintained during its subsequent period in the new thermal range (Kinne, 1964 a,b). The relationship between the stabilised rate in the new thermal range and the original normal rate in the natural habitat temperature differs between different poikilotherms depending upon the differences among them in the degree and direction of metabolic adaptation to ambient temperature. Precht (1958) has classified the metabolic adaptation to temperature into five different patterns as given in detail on the earlier section.

In most of the poikilotherms, adaptation of metabolism to temperature follows pattern 2 and 3, and this is reported in several cases of fishes such as eel, Anguilla vulgaris (Precht, 1951), the rainbow trout, Salmo gairdneri (Evans et al., 1962), (Peterson and Anderson, 1969), the toad fish, Opesanus tan (Haschemeyer, 1969), and Blennius Pholis (Campbell and Davies, 1975). However, the pattern of adaptation may vary in the same fish at different periods depending upon the differences in the thermal history and further, in the same fish, adaptation to cold and warm temperatures may follow different patterns (Parvatheswararao, 1968 a, 1971a, 1972 a,b). It is interesting to note that adaptation to temperature involves a number of active processes, making additional energy demands. The primary purpose of metabolic regulation during adaptation to temperature might be to meet such energy demands. However,
studies in this direction are very few in fishes. Most studies on fishes in this area are confined to comparing oxygen consumption to the cold-adapted and warm-adapted fishes at a few common intermediate temperatures (Scholander et al., 1958; stronganov, 1956; Kanungo and Prosser 1959 a,b; Roberts, 1967; Winberg 1956; Smirnova 1962, 1965 Wohlschlag, 1963; Haschemeyer, 1969; Parvatheswararao, 1969, 1971, a,b, 1972 a,b, 1977: sourtois, 1976). Studies of this nature are not quite sufficient in the understanding of energetic aspects of thermal adaptation as animals are often exposed to sudden changes in environmental factors, which results in the form of cold shocks or heat shocks. Therefore, it is necessary to separate the temperature resistance adaptation from greater stress phenomena in the form of cold shocks and heat shocks.

It has commonly been supposed that the increased oxygen uptake is due to the extra work of breathing following the hyperventilatory responses. The valuable estimates (Hughes, 1973; Jones and Schwarzfeld, 1974) suggest that 10% of the standard metabolism is required for the ventilatory movements under these conditions. Many fishes, especially the fresh water fishes, on account of their organisation and higher metabolism, have greater need for oxygen than the others. If the Minnows come to the surface, it is not only to catch the flies, but to have more oxygen available in the surface water. If they keep down below,
they perish. The Dipnoi, though provided with gills, must also have free access to the air, other fishes come up regularly to the surface and taking in gulps of air and from this habit several important organs have developed.

In recent times, it was found necessary and possible to distinguish the environmental-stress from the environmental adaptation, may be thermal as in this case of "temperature-stress and temperature-adaptation". Hence, in this investigation, an attempt is made in this direction and to that end heat-stress and heat adaptation as well as cold stress and cold-adaptation rate of oxygen consumption is measured in the whole fish at a gradual change in temperature (adaptation) and compared separately to the sudden and abrupt change in the temperature (stress) in both from cold to heat (heat-stress and heat-adaptation) as well as from heat to cold (cold stress and cold-adaptation) directions. In this regard, the preliminary work on differentiation of "stress" from "adaptation" process in relation to the environmental temperature has been carried out in the fish, Idus idus (Laudien and Pohl, 1975; Kunnemann and Bashamohideen, 1976; Bashamohideen and Kunnemann, 1979), in Cyprinus carpio (Bashamohideen 1984), in Tilapia Mossambica (Mushtaq Ahmd, 1988) and in Cyprinus Carpio (Abdul Rahim, 1989).

**Temperature Adaptation-Opercular Activity:**

The respiratory surface in all animals has in common the presentation to the external medium of large
surface area, often well supplied with blood vessels, across which diffusion of gases can occur. The typical respiratory organ, gills of aquatic animals including fishes have a large surface area in relation to their weight and pumping devices are often employed to renew the surrounding medium. The gills of fishes are supplied by a series of gill arches housed within a chamber formed by bony plates, the operculum, which is opened and closed rhythmically during respiratory movements. In fishes deoxygenated blood from the heart flows in the lamellae in a direction counter to that of the water flows across the exchange surfaces, this mechanism is called counter-current principle through which fish derives maximum amount of oxygen from water always fresh and rich in oxygen. The organs involved in the ventilation of a teleostean fish consists of the mouth cavity, the pharynx with its gills, and the gill covering or operculum. When a fish respires, the initial movement consists of an expansion of the hoop-like gill arches, as a result of which the mouth and pharynx enlarge. The mouth opens, and a stream of water is drawn into the oral cavity, while the external gill opening is tightly closed by the thin membrane bordering the operculum. These steps constitute the inspiratory phase.

The expiratory phase which follows immediately, consists of the closure of mouth and at the same time the contraction of the pharynx, thus directing the water towards the gills and thence through the operculum. This constitutes
the ventilatory pump. Thus, the fish's respiratory efficiency depends upon the rate of opercular movements. It has been pointed that the pulsatory movements of the opening of the mouth and operculum alternates with their closing, and it is easy to watch a fish in an aquarium (Chandy, 1970). Under environmental stress, the opercular movement can be taken as an index model to verify the respiratory activity of the animal (Thiede, 1965; Narasimhamurty, 1983, Bashamohideen, 1984). Further, according to Thiede (1965), the opercular movements can be regarded as an adequate indicator for heat-resistance in fishes. Adeney and Hughes (1977) have given the mechanisms of respiratory system with special reference to gills and branchial circulation in fishes and of water exchange across fish gills (Christopher, 1979). Studies involving the rate of opercular movement are highly conspicuous in fishes, and available work on opercular movements in fishes is confined to environmental temperature, where the process of resistance-adaptation has been reported in the fish, Rhodolus amarus as a good example (Kunnemann, 1973), where the heat resistance of the fish was determined by an increase in ambient temperature (1°C/minute), beginning from the adaptation temperature like 10°C and 20°C until cessation of opercular movements. Adjustments in extraction efficiency and ventilatory rate may also be involved in the acclimatory response and these factors, in continuation, may fully compensate for the increased oxygen tension with acclimation temperature
(Jankowsky 1968). It is clear that fish shows many adaptive responses to lowering of oxygen in the inspired water. Most of these responses are concerned with the ventilatory system and are reflex in nature, initiated by exteroceptors probably on the surface of the gills or the associated regions such as the pseudobranch. There is also evidence that there may be introceptors which respond to changes in blood oxygen levels after it has left the gills and circulates to the brain (Hughes and Ballintijn, 1965). Ventilatory responses mainly serve to increase the total amount of oxygen brought into contact with the gas exchange surfaces. (Hughes, 1981) and are also good indicators of stress situation in fishes. Thus, oxygen consumption and opercular activity, when considered together act as good indicators of pollution stress including thermal stress in fishes (Bashamohideen and Saila Bala, 1992).

**TEMPERATURE ADAPTATION : RATE OF HEART BEAT :**

The branchial or systemic heart of fishes is usually the main propultive organ for circulating the blood. From the heart, the blood first passes through the ventral aorta into the general body circulation. This process constitutes the 'Cardiac Pump' (Randall, 1968). However, the oxygen consumption representing the oxidative metabolism at the cellular level in fishes, is controlled as one of the ways by the velocity of blood circulation and on the rate of heart beat which could read the velocity of blood circulation, and in turn, the rate of heart beat and supply
of blood glucose, which is ultimate source of energy for cellular metabolism, should necessarily be undertaken. It is reported that the fish heart increased with rising temperature (Tsukuda, Liu, and Fujii, 1985; Mushtaq Ahamed, 1988; Abdul Rahim, 1989) and increasing salinity (Bashamohideen and Fazelealikhan, 1983). In goldfish, oxygen consumption per hour of the isolated heart showed similar relation to the heart rate. These result suggest some metabolic alteration in cardiac tissue with thermal acclimation.

Some investigations showed the possibility that fish heart utilizes blood lactate as an effectual energy source under aerobic conditions (Bilinsky and Jones, 1974; Gesser and Poupu, 1975; Hochachka et al., 1979; Gemelli et al., 1980; Lantin et al., 1980; Driedzic et al., 1985). The spongy endocardium which is major part of fish heart is oxygenated directly from the venous blood in the ventricular lumen (Ostadal and Schdiber, 1971; Santer, 1976). Again the spongy endocardium is supplied various substances from the ventricular lumen, consequently the isolated fish heart immersed in physiological saline must utilize exogenous lactate as an energy source under aerobic conditions. Moreover, bradycardia (slowing down of heart beat) has been observed in fishes in response to a variety of environmental changes such as salinity, temperature, atmospheric pressure, anoxia, and functional significance of many of the heart rate
changes was discussed by Randall (1968), Ruttaranee et al., (1980) and Bashamohideen and Fazelealikhan (1983). The contractile function of the myocardium and its energy provision under experimental hyperfunction of the heart in animals of different ages was well established (Stevens and Neill, 1978). Cardiac activity in general is affected by changes in blood volume by direct responses of cardiac muscle to temperature changes. Temperature acts as another neural regulator of circulation by direct action on the pace-makers in the myocardia (Randall, 1968). The positive chronotrophic effect (increased heart beat) of temperature on Winter Flounder as the water temperature increased from 10°C to 15°C. These increased cardiac rates provide an increased delivery of oxygen throughout the body which is operating at a high metabolic rate at warmer temperatures (Cech et al., 1976). Further, heart rate, as an index of oxygen intake was confirmed by Sato et al., (1978). Hughes, (1980) showed a great similarity in all the responses to hypoxia, namely, an increased ventilatory frequency and amplitude, usually a reduction in cardiac frequency followed by tachycardia, when the fish returns to normoxic conditions. Wahlqvrist and Nilsson (1980) studied on cold, where stress induced by lowering the water level, was found to have marked effects on blood pressure, heart rate and plasma levels of catecholamines.
The effect of temperature on oxygen solubility and hypoxic effect indicated on the animal, have similar effects on the rate of heart beat, and compensatory adjustments in heart rate have been reported for the shore crab, Carcinus meenas (Ahsanullah and Newell 1971) and sub-merged frogs (Jones, 1972). Most of the responses concerned with ventilatory system and cardio-vascular system are adaptive during lowering of oxygen in the inspired water of fish. These adaptive responses or changes improve the effectiveness of oxygen uptake by the blood. Many of the changes are responses to the stimulation of sense organs and are effected via reflex pathways from central nervous systems (Hughes and Shelton, 1962; Smith and Jones, 1978). These responses mainly alter the cardiac output and its distribution not only to the tissues but perhaps more importantly to the gills themselves in a way that further improves the effectiveness of oxygen uptake. It is also known that, catecholamines can affect both branchial and systemic circulation during prolonged hypoxia (Maxeaud and Maxeaud, 1981). It is evident that a rise in the temperature of water causes hypoxic condition of the medium. The responses of the cardiac pump to hypoxia result in an increased energy demand by the cardiac pump which consumes significant proportions of the standard oxygen uptake of the fish (Hughes and Saunders, 1970; Jones and Schwarzfeld, 1974). Studies involving heart beat in fishes with reference to environmental factors especially ambient temperature are highly inadequate.
TEMPERATURE ADAPTATION - RBC COUNT:

In most of the animals including fishes, blood, being the medium of internal transport that comes in direct contact with various organs and tissues of the body, the physiological state of an animal at a particular time was reflected in its blood. Studies on blood parameters have become important diagnostic tools in medicine over many years and they equally serve as diagnostic indices to investigate disease or stress in fish (Bensol et al., 1979). Studies on fish hematology have drawn a new attention with reference to its basic physiology and also hematological responses to environment (Siddique et al., 1970; Rao and Behra 1973; Dub and Dutta 1974; Raizada and Singh, 1982; Bashamohideen 1984). The effect of thermal acclimation on blood composition of gold fish (Anthony, 1961), rainbow trout (Houston and Cry, 1974), carp (Houston and Dewilde, 1968, 1969), frog (Krishnamurthi and Shakuntala, 1974), and sidewinder (Mohan and Hammer, 1974) and cattle (Olbrich et al., 1972) has been reported. Several workers have reported the haematological changes in fishes with reference to pesticides (Baynee et al., 1980), Salinity, oxygen or carbondioxide tension, on altitude and migration (Brown, 1957). Pradhan (1961) reported blood corpuscles, hemoglobin concentration and packed cell volume in Tilapia and Ophiocephalus in relation to length and weight. There are several reviews on hemoglobin and the respiratory function of the blood of plasma (Redfield, 1938; Krogh, 1941; Maxwell, 1960;
In migratory fishes, when they enter fresh water from sea, the blood becomes diluted and the number of red cells per unit volume decreases, hence the oxygen carrying capacity declines (Benditt et al., 1941). The temperature probably affects the annual cycle of oxygen concentration of red blood cells in circulation.

Smirnova (1965) found that, the concentration of hemoglobin in the blood of freshwater species from the Rybinsk reservoir is the highest in January, when the concentration of oxygen is lowest, and decreased under the more favorable summer conditions. More oxygen dissolves in cold water than in warm, so that at lower temperatures fish have less need for hemoglobin. Platner (1950) noticed that the blood of Carassius auratus, exposed to freezing temperatures in aerated water becomes diluted so that the haemotocrat blood cell volume goes down. Scholander and VanDom (1957) showed that the iron content of the blood of two cold water arctic species, out of four, examined was low. Ruud (1954) showed that the Antarctic fish, ice-fish or white crocodile fish (Chaenocephalus aceratus) is white and the colour of the gills and blood is also white and no hemoglobin in the blood. For the gaseous exchange, the gill surfaces are large, and Ruud (1958) suggested that skin respiration takes place in these fishes.
The oxygen requirements of a fish will vary according to its activity. The blood of active fish contains more hemoglobin than that of a sluggish fish (Hall and Gray, 1929; Roots, 1931; Hunn and Robinson, 1966) in order to increase its oxygen capacity. Engle and Devis (1964) measures the blood cell volume and hemoglobin concentrations of active and inactive fish, where the inactive fish showed lowest value, while the blood of active fish species possesses a greater number of red blood cells per unit volume, the oxygen capacity of the hemoglobin itself appears not to change but earlier workers (Black, 1940) suggested that, it increase with the activity of the fish. Starvation causes a reduction in the population of different cells in blood plasma. Smallwood (1916) observed that RBC count of Amia Calva dropped from 1,640,000 per cubic mm to 400,000, after starvation for 20 months. Murrachi (1959) showed in Cyprinus carpio an increased red cell sedimentation rate after starvation for 7 weeks at 6°C to 22°C and a decrease in red cell volume from 50% to 33% with a corresponding decrease in hemoglobin content from 11 to 7 g/100ml. Higginbotham and Mayer (1948) observed a reduced cell volume, hemoglobin content and blood specific gravity in Ictalurus Punctatus, where the fish were in poor conditions (Emaciation). A decline in the cell number is to mean that the fish is unable to manufacture new blood cells under starved conditions.
During the hypoxic conditions swelling of the erythrocytes and an increased haematocrit value (cell count) were observed in the rainbow trout (Holeton and Randall, 1967). The ratio of blood hemoglobin concentration to the haematocrit values is not dependent on the blood volume or on the number of red cells per unit volume (Soivio and Nikinmaa, 1981). However, new cells are liberated into the circulation during anaemia induced by bleeding (Lane 1979, Mc Leod et al., 1978). They only appear in the circulations 3-4 days after bleeding hypoxia Mc Leod et al., 1978). Further, the hypoxia induced changes in the weight of the spleen, probably the most likely site for the liberation of erythrocytes (Mc Leod et al., 1978), representing only 2% increase in the blood volume (Soivio et al., 1980).

The changes in Mean Corpuscle Hemoglobin Content (MCHC) due to the different sampling method indicate that erythrocytes obtained by cardiac puncture from stunned fish had swelled by about 10%. In addition to MCHC values of 6-day hypoxia at 18°C, indicates a marked swelling of the erythrocytes, during severe hypoxia marked increased in swelling of the erythrocytes was preserved by Holeton and Randall 1967). In hypoxia exposure at 11°C the swelling of erythrocytes was transient (Soivio et al. 1980). At 11°C water temperature changes in oxygen affinity is based totally on the decrease in ATP/Hb ratio and not on the changes in the red cell volume. However, at high temperatures (18°C)
swelling of the erythrocytes may also decrease the erythrocytic-ATP concentration, which influence the blood oxygen affinity by increasing the intraerythrocytic pH and this response takes place immediately at the onset of stress, acute hypoxia (Soivio et al., 1980).

The haematological changes, that are proving to be useful as indices include, quantifying the decrease in blood clotting time and changes in the differential leucocyte count (Mc Leay, 1975; Casillas and Smith, 1977). A decrease in the number of leucocytes (Leucopenia) has recently been found to be a significant part of the physiological response to acute stressors such as crowding (Mc Leay and Gordon, 1977). Changes in the erythrocyte counts or haemoglobin levels are most useful as indicators of haemodilution or haemo-concentration, although anaemias or stress polythermia may occasionally occur (Solvin and Oikari, 1976; Solvio and Nikimma, 1981).

When the fresh water teleost fish is exposed to hypoxia, it overcomes the oxygen demand, by increasing the oxygen carrying capacity of the blood after acclimation. Studies of Houston and Dewilde (1969) on common carp acclimated to 2, 4, 7 and 33°C revealed a direct correlation among red cell number, packed cell volume and haemoglobin content of the blood and acclimation temperature.

Therefore, the variations in the basic and highly useful haematological parameters like RBC number are valuable
indicators of stress and are also used to evaluate the changes in metabolism due to environmental alterations. But studies on RBC count regarding temperature stress and temperature-adaptation are conspicuous by their absence and such studies on hematological parameters like RBC number obviously form quick and good indicators of stress situation.

Thus the survey of literature indicates that, there is an extensive work and voluminous data existing on the general physiological mechanisms involved during thermal adaptation in poikilothersms, especially in fishes. This is the outcome of a great deal of work investigated for several decades in the field of temperature adaptation. But, in recent times, it was found necessary to distinguish this adaptation may be thermal or osmotic or any other from other phenomena, "Stress-effects" and "Stress-adaptation" which could be easily mistaken for these adaptations in general. Thanks to the pioneering work of Precht and his collaborators for this new approach on adaptation processes. When the poikilothersmic animals are subjected to thermal changes and when the process of acclimation is complete, one has to differentiate between possible "temperature-stress" from "temperature-adaptation". It appears normal metabolism of adaptation is switched off and the mechanisms concerned with the process of stress are switched on and vice versa. However, presence of an indicator (metabolite, hormone etc.,) typical only for the stress situation is yet to be
established. Therefore, an attempt is made in this investigation to differentiate temperature-stress from temperature-adaptation and to decipher the physiological mechanisms involved during temperature-stress and temperature-adaptation in a eurythermal fresh water fish, *Labeo rohita*. 