SUMMARY
1. Energetics as measured by different parameters such as oxygen consumption, 
opercular activity, rate of heart beat, RBC count, blood glucose, liver glycosen level, 
energy rich adenylate nucleotides like ATP, ADP, AMP and energy charge and 
ATPase activity in different tissues like gill, kidney, intestine, brain, liver, red muscle 
and white muscle in the common carp, *Cyprinus carpio* subjected to thermal-adapta-
tion and thermal-stress have been studied in this investigation.

2. The experimental fish, *Cyprinus carpio* weighing 15gm ± 1gm were collected from 
the local Government Fisheries Department and adapted to laboratory conditions 
and maintained at the normal room temperature (25°C ± 0.5°C).

3. For the basic experimental purposes, one batch of the fishes of lab temperature 
(25°C) were adapted to 20°C and other batch of fishes of were adapted to 30°C 
through the estimation of oxygen consumption daily, till it reached a constant value. 
For adaptation to lower temperature (20°C) a 12 days sojourn and for adaptation to 
higher (30°C) a 8 days sojourn were allowed. As the new stabilised level in oxygen 
consumption is approximately in between the original normal level of the room 
temperature and the initial shoot-down level or the initial shoot-up level as the case 
may be. Thus, in *Cyprinus carpio* adaptation of oxygen consumption for the cold and 
warm temperatures is only partial (type 3 of precht classification).

4. In order to distinguish and differentiate temperature stress (heat-stress and cold-
stress) phenomenon from temperature-adaptation (heat-adaptation and cold- adap-
tation) the 20°C and 30°C temperature adapted fishes were re-adapted in the 
following patterns

i) The 20°C temperature adapted fishes were re-adapted to a slow rise of ambient 
temperature from 20°C to 30°C at the rate of 1°C/60 hrs (2 1/2 days; heat-adapa-
tion).

ii) The 20°C temperature adapted fishes were re-adapted to an abrupt rise of 
ambient temperature from 20°C to 30°C *Cyprinus carpio* at the rate of 1°C/hr 
(heat-stress).
iii) The 30°C temperature adapted fishes were re-adapted to a slow temperature change from 30°C to 20°C at the rate of 1°C/60 hr (2 1/2 days; cold-adaptation) and iv) The 30°C temperature adapted fishes were re-adapted to an abrupt temperature change from 30°C to 20°C at the rate of 1°C/hr (cold-stress) and thus, the experimental fishes were grouped under four categories, namely heat-adapted, heat-stressed, cold-adapted and cold-stressed.

5. The 30°C adapted fishes showed a higher rate of oxygen consumption and opercular activity when compared to 20°C adapted ones, indicating greater energy demands of the fish during adaptation to higher temperature.

6. In the case of Cyprinus carpio which are subjected to a slow temperature change from 20°C to 30°C (heat-adaptation) at the rate of 1°C/60 hr (2 1/2 days), the time-course experiments with reference to basic physiological parameters like the rate of oxygen consumption and opercular activity shows a gradual stepping up of these two parameters, and ultimately, reached the control values 30°C adapted within the 35 days of exposure period. During cold-adaptation from 30°C to 20°C at the rate of 1°C/60 hrs (2 1/2 days), there is a gradual stepping down in the rate of oxygen consumption and opercular activity and ultimately reached the control values of 20°C temperature adapted control fishes, within 35 days of exposure period as resulted in the maximum per cent increase with a complete recovery in these two parameters in both heat-adaptation and cold-adaptation without physiological load on the part of the fish.

7. On the other hand, in the case of fishes exposed abruptly to a temperature change 20°C to 30°C (heat-stress) and from 30°C to 20°C (cold-stress) at the rate of 1°C/hr, there is no stepping up/stepping down respectively of oxygen consumption and opercular activity in both heat-stressed and cold-stressed fishes, and the values in these two parameters could not reach the control values even over a period of 35 days. Further, in stress situation, these two factors fluctuate considerably with greater magnitude in their levels over a longer period and continued stress acting upon this fish culminates ultimately in the situation of 'stress-adaptation' with a far less percent increase and percent recovery in these parameters during stress. Obviously, this is due to the physiological load acting upon this stressed fish. Thus, temperature-adaptation (heat-adaptation and cold-adaptation) is different from temperature-stress (heat-stress and cold-stress).

8. Cyprinus carpio adapted to 30°C registered a relatively higher rate of heart beat and RBC number when compared to that of 20°C temperature adapted fish. In these haematological parameters, namely, the rate of heartbeat and the RBC number, the heat-adapted fishes exhibited a gradual elevation in both these parameters, and the
cold-adapted fishes exhibited a gradual decrease in the rate of heart beat and RBC number, showing a linear relationship between the two factors in both the types of adaptations. Further, these two parameters reached the control values with a relatively higher percent increase and complete almost recovery. However, the per cent recovery is relatively higher in the case of heat-adaptation than that of cold-adaptation. On the other hand, these haematological parameters, the rate of heart beat and RBC count, exhibited in a different way in that they fluctuate to a greater extent in the initial periods of stress (both heat-stress as well as cold-stress) situation followed by a greater decline in their levels especially with the operation of bradycardia (slowing down of the rate of heart beat) which is observed in the stressed fishes, and it is the indicator of stress situation in the fish Cyprinus carpio. Unlike in the heat adapted and cold-adapted fishes, the per cent recovery in the rate of heart beat and RBC number are relatively brought down to a much lower level by dint of undue burden on the part of the fish during heat-stress and cold stress situation, probably with a rapid or steady release of energy.

9. With regard to energy sources there is a precise inverse relationship between the blood glucose level and liver glycogen content during adaptation to higher temperature (heat-adaptation) as well as adaptation to lower temperature (cold-adaptation) in the fish Cyprinus carpio. During adaptation to higher temperature i.e., heat-adaptation, there is a steep increase in the blood glucose level with a concomitant decrease in the liver glycogen content, suggesting that blood glucose is derived from the hepatic glycogenolysis to meet the higher energy demands during heat-adaptation. During the cold-adaptation, a reverse trend is observed in that, there is a steep decrease in the blood glucose level and a gradual increase in the liver glycogen content, indicating the restoration of liver glycogen during the process of cold-adaptation. The reaching of the controls was observed in these two parameters in heat-adapted and cold-adapted fishes (with a maximum increase of 159.03% in blood glucose and maximum percent decrease of 83.33% in liver glycogen during heat adaptation and maximum decrease of 56.38% in the blood glucose level and a maximum percent increase of 89.31% in the liver glycogen during cold adaptation were observed. Further, the adapted fishes exhibited a fairly good amount of recovery (i.e., 94.71% in blood glucose and 91.25% in liver glycogen during heat-adaptation, and 83.33% in blood glucose and 79.56% in the liver glycogen during cold-adaptation). However, the relative percent recovery in significantly higher in heat-adaptation when compared to cold-adaptation. But the heat-stressed and cold-stressed fishes could not show any indication of reaching the control values nor
complete recovery in these two parameters, namely, the rate of heart beat and RBC count was observed.

10. Regarding the energy rich adenylate nucleotides, a higher level of ATP and energy charge and a corresponding lower level of AMP and ATPase activity, with an intermediate level of ADP between ATP and AMP was noticed in all the tissues like gill, kidney, intestine, brain, liver, red muscle and white muscle in both cold (20°C) and heat (30°C) adapted fishes. The inverse relationship of higher concentration of ATP and lower concentration of AMP resulted in the fully charged adenylate system, indicating the prevalence of high energy charge. The energy charge \((\frac{ATP + \frac{1}{2}ADP}{ATP + ADP + AMP})\) was found to be greater in the order of brain>liver>kidney>gill>red muscle>intestine>white muscle in both cold adapted and heat adapted fishes.

11. The heat adapted fishes registered an increase level of ATP and energy charge with concomitant lower levels of ADP, AMP and ATPase activity when compared to cold adapted fishes in all the tissues indicating the higher energy demand hence greater turnover of ATP on adaptation to higher temperature medium, which is perhaps in more stressful than the lower energy demand on adaptation to lower temperature medium. In the case of heat adapted fishes during time course experiments, there is a gradual stepping up in the levels of ATP and energy charge and a gradual stepping down in the levels of ADP, AMP, and in the activity of ATPase in all the tissues. Further, there is a complete filling up processes in the ATP and the values reached gradually the original level of these parameters of the controls of 30°C adapted fishes. The heat adapted fishes exhibited a fairly good amount of recovery ranging from 73% to 96% in these adenylate nucleotides. The percent recovery in these parameters during heat adaptation found to be greater in the order of brain>liver>kidney>gill>red muscle>intestine>white muscle. However, in the case of cold adapted fishes which are subjected from 30°C to 20°C with a slow raise of temperature, the change in adenylate nucleotides and ATPase activity are diametrically opposed when compared to heat-adaptation. Where there is a gradual stepping down of ATP and energy charge, there is a corresponding stepping up of ADP, AMP & ATPase activity. These cold-adapted fishes are also recorded a good amount of recovery (64.32% to 90.65%) but significantly lower than the heat-adapted fishes. This indicate that the energy demands hence, the energy turnover is significantly lower in the cold-adapted fishes than in the heat adapted ones.

12. On the otherhand in the temperature-stressed fishes (heat-stressed and cold-stressed) which are subjected to an abruptly temperature change from 20°C to 30°C and 30°C to 20°C respectively, at the rate of 1°C/hr, these adenylate nucleotide did
not reach the control values as the filling up processes with ATP were not complete. Further, the per cent recovery in these parameters is far less (48.00% to 57.72%) when compared to temperature adapted fishes. However, the heat-stressed fishes exhibited a greater level of per cent recovery which is significant over the per cent recovery observed in the cold stressed fishes (34.48% to 54.47%). This indicates that heat adapted fishes may be thermally more efficient than the cold adapted ones. These heat stressed and cold stressed fishes established new levels of ATP, ADP, AMP, energy charge and ATPase activity in all the tissues. The continuous thermal stress (1°C/hr) acting upon the fish *Cyprinus carpio* resulted in stress-adaptation (adaptation resulted due to stress). The per cent recovery in both heat adapted and cold adapted in these adenylate nucleotide parameters was found to be greater in the order of brain > liver > kidney > gill > red muscle > intestine > white muscle.

13. Of all the tissues, brain is found to be fully charged with ATP, hence with maximum energy charge, whereas white muscle is found to be least charged with ATP, hence with minimum energy charge in both heat and cold adapted fishes. Amongst the osmoregulatory tissues, kidney followed by gill recorded a high energy charge with a correspondingly low ATPase activity and amongst the non-osmoregulatory tissues brain and liver were maximumly charged with ATP. Red muscle which is found to be more aerobic in its oxidation is found highly charged with ATP when compared to white muscle with an intermediate level of ATP charge in intestine. When the ATP level, hence the energy charge are found to be higher, the level of ADP, AMP and ATPase activity are decreased in all the tissues. This indicates the hydrolysis of ATP is brought about by the activity of ATPase releasing, ultimately the greater amount of AMP for least energy charge in the tissues. Of all the tissues brain and liver among non-osmoregulatory tissues, followed by kidney and gill among osmoregulatory tissues, are found to be recovered maximumly during thermal stress and thermal adaptation. The per cent recovery in red muscle, intestine and white muscle are found to be less when compared to the other tissues. Thus brain among the non-osmoregulatory tissues, kidney among the osmoregulatory tissues are thermally more potent tissues with maximum capacity to recover from thermal stress. This is obvious that brain is greatly concerned in integrating and co-ordinating various thermal compensating mechanisms and kidney having very important role in the hyper osmotic medium like fresh water is actively eliminating the excess water from the body of the fish in to the dilute fresh water medium.

14. These studies on thermal-stress and thermal-adaptation in *Cyprinus carpio* clearly indicate that an abrupt temperature change at the rate of 1°C/hr within the
normal level of temperature from 20°C to 30°C (heat-stress) and from 30°C to 20°C (cold-stress) acts as a stressor to *Cyprinus carpio* and temporarily inhibits the adjustment of metabolism to the new temperature change. Hence, stress is a physiological load acting upon the fish and the factors causing stress are termed as 'stressors', such as temperature of the present study, and continuous stress acting upon the fish resulted in the process stress-adaptation.

15. However, a very slow temperature change, within the normal range, from 20°C to 30°C (heat-adaptation) and from 30°C to 20°C (cold-adaptation) at the rate of 1°C/60 hrs (2 1/2 days), in *Cyprinus carpio*, resulted in the process of adaptation, as a slow process of compensation without physiological load on the part of this fish. Thus, 'stress' is entirely different from 'Adaptation' and these two processes could be differentiated on the basis of re-adaptation experiments as shown in this investigation, with due importance to the rate of thermal exposure.

16. Further from these findings on 'temperature-adaptation' (heat-adaptation and cold-adaptation) and "temperature-stress" (heat-stress and cold-stress), it appears as though in this carp *Cyprinus carpio* that when the fishes are in the situation of stress, the normal mechanisms of adaptation are switched off and the mechanisms concerned with stress phenomenon are switched on and vice versa. A high degree of fluctuations in the physiological and biochemical parameters observed in the early phase of stress situation represents as good indicators of temperature-stress in this fish.

17. Thus, when poikilothermic animal subjected to any environmental change, may be thermal, as it is in the present study, osmotic or pollutional, and when the acclimation is complete, it was found out from the present investigation that it is necessary and possible and one has to differentiate the adaptation process from other phenomenon like 'stress effects' which could be easily mistaken for the adaptation processes, coming across in the thermal regime of the animal. An all embracing concept of adaptation is not advisable.

18. Studies of this nature which could differentiate from environmental-stress from environmental-adaptation with reference to ambient temperature are highly useful in the evaluation of rates of temperature which act as stressor and induce stress situation, on one hand, and on the other in the evaluation of 'safe' and 'ideal' rates of temperature which do not act as stressors but, result in the slow and easy compensation of adaptation without physiological load on the part of the animal. Thus, studies of this nature are highly appreciable in evaluating methods and techniques concerned with safe rearing and conservation of useful fauna of the aquatic habitat.