# STUDIES ON SOME BORING AND FOULING CRUSTACEANS

By

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THESIS

Submitted to the University of Cochin
in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

1977

## CERTIFICATE

This is to certify that this thesis is an authentic record of the work carried out by Mr. C.J. Cherian, M.Sc., under my supervision in the University Department of Marine Sciences and that no part thereof has been presented before for any other degree in any University.

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Ernakulam
12-4-1977

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C.J. CHERIAN

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# I

## GENERAL INTRODUCTION

Timber has proven an ideal material for the construction of underwater structures ever since man began his encounter with the sea. But the organisms which directly or indirectly cause deterioration of underwater timber structures, including ships and boats, attracted his attention only in the 18th century, when the low-lying lands of the Dutch coastline were in danger of being flooded as a result of the failure of the wooden dykes seriously damaged by shipworms. Since then marine boring and fouling organisms have been the subject of detailed investigations and Sellius (1733) who initiated the studies on shipworms is considered the pioneer in the field of marine borer research. During the course of more than two centuries, many aspects of the biology and physiology of these organisms have been brought to light. However these works lie dispersed in a large number of publications. The exhaustive information on marine borers published till 1954 has been excellently compiled by Clapp and Kenk (1963). Reviews of marine borer research are also available in the works of Menzies (1957), Becker (1958), Ray (1959), Turner (1966), Pillai (1961, 1967), John (1968), Nair and Saraswathy (1971), Purushotham and Rao (1971, 1971a), Jones and Eltringham (1971) and Cheriyan (1973). Regarding foulers, the monograph brought out by Woods Hole Oceanographic Institution (1952) has been very useful. Information on fouler research in India is available in the reports of Purushotham and Rao (1971, 1971a).

fauna and flora within the burrow. But Ray and Julian (1952) observed cellulase in the intestinal diverticula of Limnoria and proved that it can digest wood. Sphaeromids apparently do not eat wood as it is evident from the fact that their burrows do not exceed 10 - 20 mm in length. But John (1968) has been able to demonstrate the presence of cellulase in Sphaeroma terebrans.

Fouling organisms are plants and animals which are found attached to the surface of submerged objects. Nearly 2,000 species of plants and animals have been reported as foulers in the marine environment. They are widely distributed among the existing groups of organisms, from Protozoa to Pisces. The animals and plants which take part in fouling are primarily the attached or sessile forms. As they develop, the character of the surface changes and places are provided where many free living organisms may find shelter and food. This results in the inclusion of organisms quite incapable of acting as independent foulers, to the fouling community and cannot be separated from it on any reasonable grounds (Woods Hole Oceanographic Institution, 1952). Separation on the basis of freedom of movement is difficult since some sessile animals like Mytilus and Modiolus are able to move from one place to another, while some motile forms like the Chiton can cling to smooth surface with the firmness which resists the most violent water movements. Consequently the concept of fouling has been quite elastic and it remains to be an entity not well defined. Earlier authors ignored some groups, notably the free living and microscopic

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forms in regard to the composition of fouling. The importance of the need for the inclusion of the free moving forms also in the fouling community has been duly recognised by recent workers in this field and several of such animals like foraminiferans, nemerteans, copepods, nudibranchs, gastropods and even certain fishes have been listed as components of the fouling community (Woods Hole Oceanographic Institution, 1952). Even though destruction by fouling is not much, the problem has been very serious in many other ways. The most widely known effect is on the efficiency of propulsion of sea-going vessels. It is estimated that as much as 200 tonnes of fouling may be removed from a ship's bottom at a single docking (Woods Hole Oceanographic Institution, 1952). Visscher (1928) stated that $ 100,000,000 was spent annually by United States shipping interests alone, because of fouling. Fouling gives serious troubles when it occurs in pipes and conduits used to conduct water. It may also reduce the efficiency of underwater acoustic devices. It is generally considered that fouling is most severe in tropical waters where growth is rapid and where there is little seasonal interruption of the reproductive processes.

India has a coastline of about 4,000 km and is expending millions of rupees on underwater timber structures like piles, jetties, fenders, boats, catamarans, Chinese nets, stake nets, etc. A recent survey conducted by the Forest Research Institute has revealed that in Kerala State alone about Rs.115 lakhs is spent annually for the maintenance of

wooden structures like mechanised and non-mechanised boats, stake net poles, Chinese net poles etc. used in fisheries operations only. The amount will be much more when the maintenance charges of wooden structures in harbours and jetties, passenger boats and country boats, sluice gates etc. are also taken into consideration. Despite the economic importance of the problem, these organisms received little attention in India and the marine borer and fouler research here is very recent. It was Erlanson (1936) and Beeson (1936) who initiated the studies on these organisms in India. Towards the middle of 1950s biologists in India began to look into the problem and since then a vast body of information on the systematics, biology and ecology of the wood-boring and fouling organisms of the Indian coasts has been brought to light (Purushotham and Rao, 1971; 1971a).

In spite of the research done for over two hundred years in several parts of the world, we have not been able to penetrate beyond the fringe of the problem of marine fouling and boring. The magnitude of the problem has drawn more attention in the last fifty years and a stage has been reached now that the organisms involved are fairly well known though not much about their behaviour and the methods to prevent the destruction caused by them. In recent years increasing attention has been focussed on an approach which is based on the concept that a thorough knowledge of the behaviour and functions of an organism in relation to the habitat is essential for developing methods and material for controlling their activities. A comprehensive knowledge of the

habits and relationships to environmental factors of these organisms is of decisive importance for the testing and application of protective measures against their activity.

It is known that closely related species may have different life history patterns, different anatomical features and different reactions even though superficially they appear quite similar. Moreover, it has become increasingly clear that nearly every phase of scientific enquiry is greatly benefited by comparative studies. These often reveal relationships between phenomena that are not always apparent. An understanding of such correlations may lead to the emergence of new approaches to the problems. Besides, the exploitation of the difference in the behaviour of organisms has been the basic idea of all attempts to control or kill one organism without disturbing another. Even though the importance of the study of the nature of physiological adaptations and variations in animal populations has been stressed by many authors like Prosser (1955, 1958) and Bullock (1955), such works on the boring and fouling organisms especially on the crustaceans have been very little. Some of the few ecophysiological studies on the wood-boring and fouling crustaceans of India are those of Ganapati and Prasada Rao (1960, 1962), Prasada Rao and Ganapati (1968, 1969), Nagabhushanam and Gopalakrishnamurthy (1965, 1965a), George (1967), Cheriyan and Cherian (1968) and Cheriyan (1973).

The present work comprises studies on the salinity tolerance and respiratory metabolism of a wood-boring sphaeromid, Sphaeroma

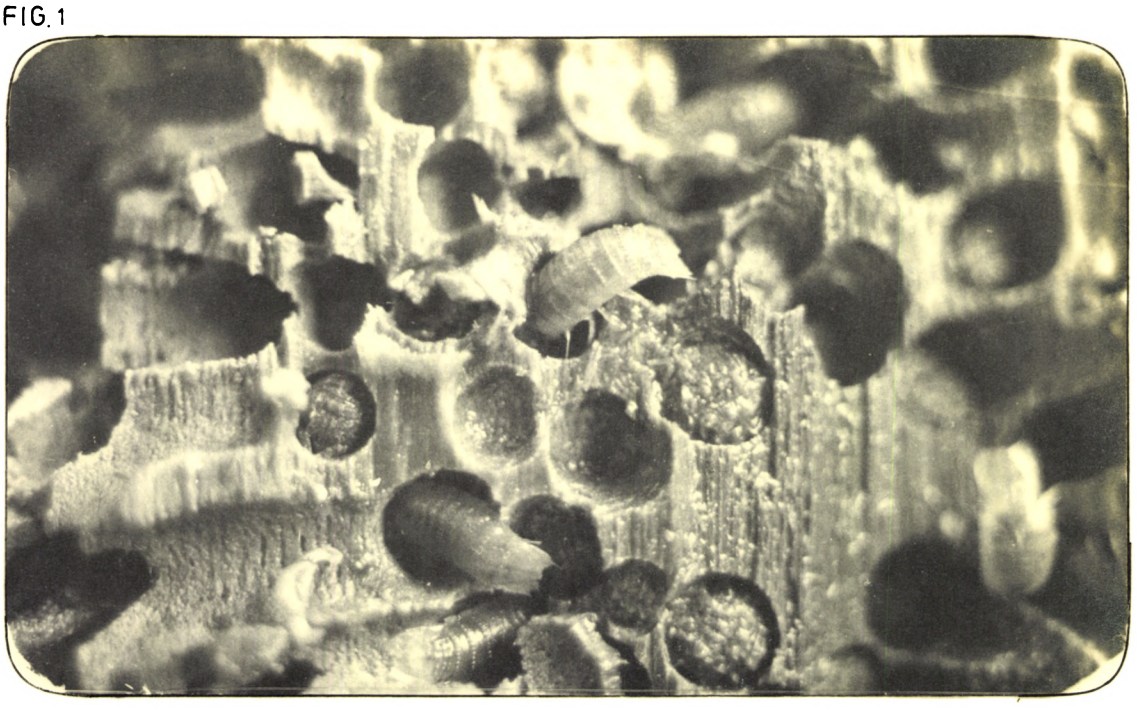
annandalei, Stebbing and two free living foulers of the family Cirolanidae, Cirolana fluviatilis Stebbing and C. willeyi Stebbing. Except for the systematic accounts and general observations by Pillai (1961) and the preliminary studies on the salinity tolerance and respiration of C. fluviatilis by Nagabhushanam and Gopalakrishnamurthy (1965, 1965a) very little is known about these isopods from Indian waters. Studies by John (1968) on the habits, structure, and development of Sphaeroma terebrans and by Cheriyan (1973) on the ecophysiology of the same are the recent major contributions on this interesting group of animals. S. annandalei is closely related to S. terebrans and has been reported to occur on timber along with the latter (Pillai, 1961). S. annandalei is a serious pest attacking wood along the Kerala coast, but detailed works on this species have not been undertaken so far.

Cirolana fluviatilis and C. willeyi are two free living foulers, very common in the estuaries of Kerala coast. They are often seen in the burrows of borers and are likely to be mistaken as true borers. Observations under laboratory conditions revealed that they are carnivorous and natural enemies of wood-borers and foulers, feeding on living and dead organisms especially shipworms, sphaeromids and barnacles (Fig.1).

Search for methods of controlling the pests causing deterioration of submerged timber has been generally aimed at developing some chemical or physical barriers. Only in recent years biological control,

PLATE 1

FIG. 1



A

B

the basic idea of which is to use one organism against the activity of another has been successfully exploited. In the field of wood preservation in marine conditions nothing is known to have been done on these lines. It has been proved in many cases that the intensity of an organism in a locality could certainly be influenced by the occurrence and intensity of its natural enemies. Sellius (1773) suggested that an increase in the number of the enemies of shipworms may check their ravages. But attempts to explore the potentialities of this type of biological control are still to be carried out. The failure so far of preservatives against marine borers and foulers stresses the importance of such studies. The observation that Cirolana fluviatilis and C. willeyi are predators of wood-borers and foulers makes these animals economically important and it was felt that further studies on these natural enemies of those serious pests would be rewarding.

## II

## DESCRIPTION OF SPECIES

| | | |
|---|---|---|
| Order | - | Isopoda |
| Sub-Order | - | Flabellifera |
| Family | - | Sphaeromidae |
| Group | - | Hemibranchiatae |
| Genus | - | Sphaeroma Bosc |

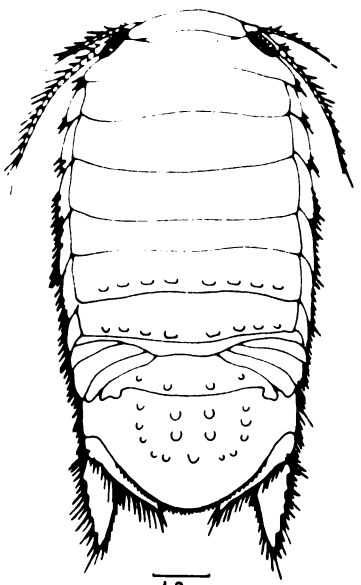
### Sphaeroma annandalei Stebbing (Fig. 2)

Stebbing, 1911; Barnard, 1936, 1940; Pillai, 1961

Diagnostic features: Only the posterior half of the thorax is tuberculate. Distal border of telson semicircular. Two pairs of submedian tubercles followed by a median tubercle and flanked by 3 tubercles in a longitudinal row on either side of the median tubercle. Tubercles non-setose.

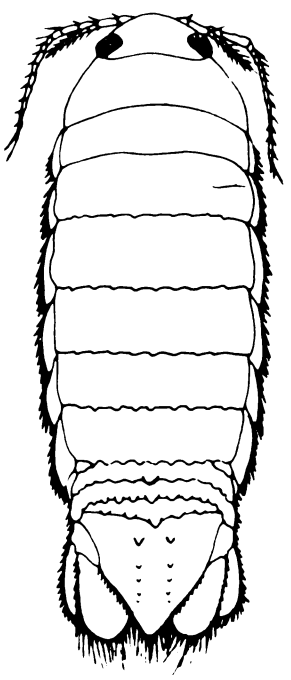
S. annandalei has been recorded from South Africa and India. In India it has been reported as a very serious wood-borer at Cochin, Neendakara, Vellar and Godavary estuaries. It has been also recorded from Visakhapatnam and Bombay. Pillai (1961), Purushotham and Rao (1971) and Cheriyan (1973) have reported that this species is present in the sea as well as in the estuarine and brackishwater localities. But during the present study S. annandalei was not observed in the open sea. Instead, they were seen only in far away places of the estuarine region often

PLATE 2



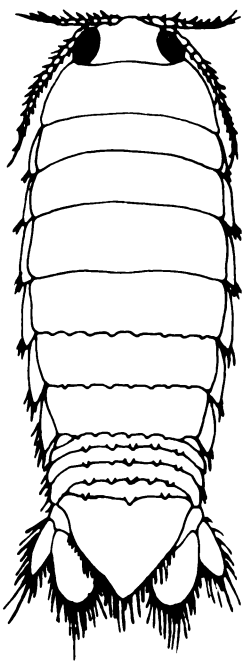
1.0mm

FIG. 2 Sphaeroma annandalei



1.0mm

FIG. 3 Cirolana fluviatilis



1.0 mm

FIG. 4 Cirolana willeyi

attacking the sluice gates of the paddy fields used for prawn culture.

Being a peracaridan, development of the young in this species takes place in a brood pouch and the young ones leave the brood pouch in an advanced state of development. The young ones in a brood vary from 20 to 50. Breeding is apparently continuous. The young ones live in the burrow of the mother clinging to the ventral side of its body for some time and later begin to excavate new burrows attached to the old one or move out and find new places of attack. The burrows are straight, often 10 - 20 mm deep according to the size of the animal. In each burrow the animal just fits in and the head is turned to the blind end of the burrow. The telson is always visible from outside, permitting a rapid identification of the species without being taken outside the burrow. When forced to quit the burrow, the animal swims in the water with the ventral side of the body upward and find another place of shelter. Inside the burrow they are capable of producing strong water currents by the beating of pleopods. They are also capable of producing a chirping sound when disturbed. It is observed that the production of sound is effected by some action of the uropods and telson on the surrounding wood. However, it was observed that the production of sound is more pronounced in S. terebrans. The burrows become close together separated by only a thin film of wood, when the attack is severe and the timber presents a typical honeycomb appearance. The attack of Sphaeroma is mainly concentrated at the intertidal portion of

the timber structures (Pillai, 1967; John, 1968 and Cheriyan, 1973).

Family - Cirolanidae

Genus - *Cirolana* Leach

*Cirolana fluviatilis* Stebbing (Fig. 3)

Stebbing, 1902; Barnard, 1920, 1935, 1940; Chilton, 1924, 1926; Pillai, 1961.

Diagnostic features: Telson trianguar with two submedian teeth near the base followed by two parallel longitudinal rows of 3 or 4 denticles forming a pair of ridges. Semi-transparent greenish yellow in colour.

*Cirolana willeyi* Stebbing (Fig. 4)

Stebbing, 1904; Chilton, 1924; Barnard, 1935; Pillai, 1961.

Diagnostic features: Telson triangular, apex narrow and rounded with 8 spines. Pleon segments 2 - 4 with 5 teeth, fifth with 3; the median tooth on each pleon segment slightly larger. Dark grey in colour with a broad median dark area widening posteriorwards. Laterally the chromatophores form reticulate patterns.

Both the species have been reported from South Africa, Ceylon and India. In India they are very common in the estuarine and brackish water localities of Cochin, Neendakara and Chilka lake. *C. fluviatilis* has been reported from Madras and Visakhapatnam also. It has been wrongly identified as *C. pleonastica* by some authors (Pillai, 1961).

Both the above species of Cirolana are swift moving and very common on submerged timber. Very often they are found in the burrows of borers and are likely to be mistaken as wood-borers. Usually they avoid light and are found hiding in the burrows, crevices and empty shells of foulers. Members of the family Cirolanidae are carnivorous and many species are considered as efficient scavengers (MacGinitie and MacGinitie, 1949; Ricketts and Calvin, 1962). In the laboratory it has been observed that a group of fifteen or twenty animals are capable of eating up one entire specimen of a 2 - 3 inch long shipworm, within a few minutes. Wood-boring sphaeromids are also their favourite food. Perinereis sp., a polychaete which is also common on submerged wood and considered to be an enemy of shipworms is another victim of Cirolana spp. When a piece of shipworm or an injured Sphaeroma is put in the aquarium tank where these animals are kept they become aware of it and come out of their hiding places within 10 - 20 seconds and feed on it leaving behind only the hard parts. They are so voracious that after feeding the body swells to the extent of hindering their swift movement. As in Sphaeroma, development of the young ones takes place in a brood pouch. The young ones in a brood varies from 5-15. Breeding is throughout the year and the young ones liberated from the brood pouch are very active in movement and feeding.

# III

## STUDIES ON THE SALINITY TOLERANCE

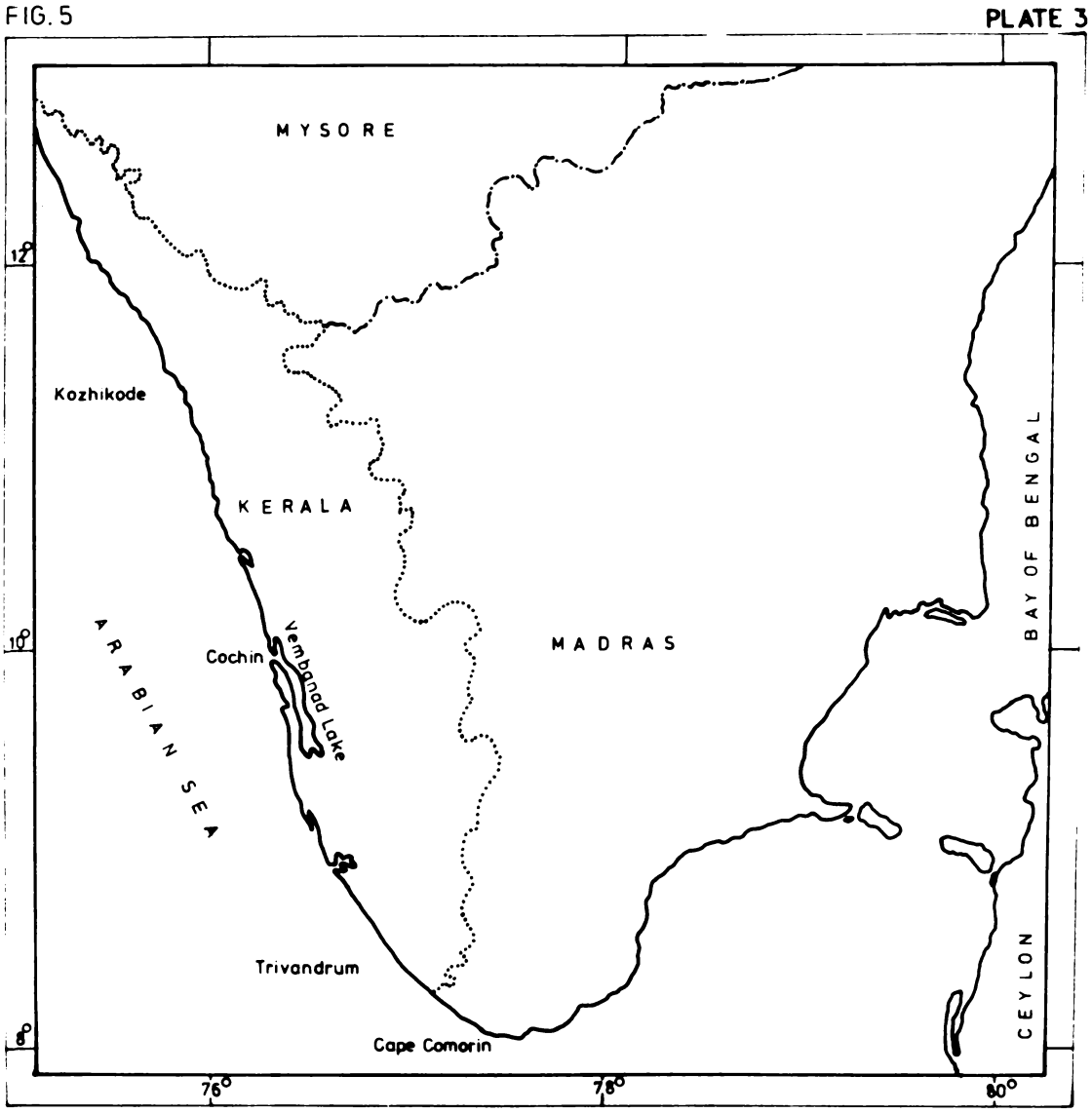
### (i) Introduction

Salinity represents an environmental master factor in marine and brackish water areas and hence the study of organismic responses to salinity variations is a pre-requisite for an understanding of the eco-physiology of marine organisms. It has been evidenced by a large number of papers that there exists a complex correlation between temperature and salinity. But where fluctuations in temperature are not significant as in the case of many tropical waters, salinity can be considered as the most potent physical factor affecting life. Studies on the effects of salinity on marine and brackish water organisms are relatively fewer compared to those on the influence of temperature. Reviews on the effects of salinity on marine organisms are available in the works of Beadle (1957), Black (1957), Pearse and Gunter (1957), Robertson (1957, 1960), Moore (1958), Remane and Schlieper (1958), Nicol (1960), Prosser and Brown (1961), Lockwood (1962), Newell (1970), Kinne (1971) and Vernberg and Vernberg (1972).

Sphaeroma annandalei, Cirolana fluviatilis and C. willeyi are abundant in the Cochin backwaters which is the northern part of the Vembanad Lake situated in the Kerala State, South West Coast of India. The Vembanad Lake which is the biggest and most extensive one in Kerala is situated between latitudes 9° 28' and 10° 10' North and longitudes 76° 13' and 76° 31' East( Fig. 5). Its length is about 115 km and

FIG. 5

PLATE 3


MYSORE
12°
Kozhikode
KERALA
ARABIAN SEA
10°
Cochin
Vembanad Lake
MADRAS
BAY OF BENGAL
Trivandrum
CEYLON
8°
Cape Comorin
76°
78°
80°

breadth upto 15 km. Near the northern end of this lake is situated the port of Cochin where the lake is permanently connected to the Sea by a narrow channel. A number of important rivers of Kerala discharge into the lake so that during the Monsoon season they carry enormous quantities of fresh water to the lake. The hydrographical conditions in this region are thus largely influenced by the heavy rainfall during the Monsoon season and by the adjoining sea in the other seasons, presenting a typical tropical estuary. Hydrographical studies in and around Cochin from where the specimens for the present study were collected have shown that the temperature variations are within the limits of 24 - 32°C while salinity varies widely from that of fresh water to 34‰ (Table 1; also Cheriyan, 1963, 1967a; Shankaranarayanan and Qasim, 1969). Field observations on Cirolana willeyi, C. fluviatilis and Sphaeroma annandalei showed that all these three closely related isopods are euryhaline but exhibiting varying patterns of seasonal and spatial distribution. Since a detailed evaluation of the tolerance limits to salinity variations requires both information obtained in the field and under controlled conditions in the laboratory, experiments were conducted on healthy animals to study their responses to normal as well as various subnormal and supranormal salinities.

### (ii) Materials and Methods

Based on the variations of salinity in the Cochin backwaters, three hydrographical seasons can be made out during an year viz. Monsoon

season (June - August) Post-Monsoon season (September-December) and Summer season (January-May). As a result of the fresh water influx due to heavy rains and strong flow from the rivers, the Monsoon season is characterised by very low salinities, often below 1‰. During the post-Monsoon season the salinity gradually rises up and the area attains marine conditions during the summer season. In order to study the survival of the animals during these three seasons, experiments were conducted using specimens collected during each season. In the Monsoon season, specimens were collected when the salinity was 1‰. Similarly specimens were collected during the post-Monsoon and summer seasons when the salinity reached 17‰ and 33‰ respectively. Animals collected from the field from wooden structures like jetty piles, sluice gates, etc. were kept in laboratory aquaria along with the timber pieces on which they are found. Cirolana spp. were fed with pieces of molluscan and crustacean meat occasionally. But nothing particular was given to Sphaeroma annandalei since they had enough of timber and marine algae in the aquarium tanks. The water in the aquaria was continuously filtered and aerated for two hours twice a day using the device described by Cheriyan (1967). The animals were thus acclimatised for 15 days before the salinity tolerance experiments were started.

Three series of experiments were carried out using animals acclimated in salinities 1‰, 17‰ and 33‰, representing the three hydrographical seasons prevailing in the area. Various dilutions of

Table 1. Temperature and Salinity variations in the Cochin harbour area during 1969 - 1971. (Average of weekly data collected at 9 A.M. at the Department of Marine Sciences Jetty near the Ernakulam Channel)

| Months | 1969 | | 1970 | | 1971 | |
|---|---|---|---|---|---|---|
| | Temp.°C | Sal. ‰ | Temp.°C | Sal. ‰ | Temp.°C | Sal. ‰ |
| Jan. | 29.5 | 32.7 | 28.9 | 31.8 | 29.9 | 31.9 |
| Feb. | 30.7 | 33.5 | 30.2 | 32.5 | 30.2 | 32.5 |
| Mar. | 31.6 | 33.9 | 31.2 | 33.3 | 31.1 | 32.7 |
| Apr. | 32.5 | 33.8 | 31.9 | 32.9 | 31.2 | 33.3 |
| May | 32.3 | 34.0 | 31.7 | 29.5 | 31.5 | 21.1 |
| Jun. | 29.4 | 9.3 | 28.5 | 14.0 | 27.9 | 0.8 |
| Jul. | 27.2 | 0.6 | 27.9 | 1.0 | 28.2 | 0.7 |
| Aug. | 29.4 | 3.7 | 29.7 | 2.8 | 29.2 | 4.9 |
| Sept. | 29.6 | 13.1 | 29.8 | 10.5 | 29.1 | 7.4 |
| Oct. | 29.7 | 11.1 | 29.3 | 14.3 | 29.5 | 15.8 |
| Nov. | 30.3 | 22.6 | 29.3 | 24.9 | 29.7 | 25.1 |
| Dec. | 28.8 | 29.2 | 28.8 | 28.9 | 27.6 | 29.0 |

sea water were prepared by adding adequate quantities of re-aerated distilled water to double filtered sea water. Higher salinities than normal sea water were prepared by evaporation of the same in the air. Salinities were determined by titration against silver nitrate solution using the formula of Knudsen (1901). The animals were washed once with the water of the same salinity to which they were to be transferred, prior to the beginning of each experiment. Juveniles and berried ones were not included in the experiment. For each salinity 200 ml of the water was placed in a glass beaker and 5 - 10 animals were transferred to each salinity. The temperature was maintained at 28.5 $\pm$ 1°C. The animals were checked at short intervals and the duration of each experiment was 10 days. The range of salinities causing mortality was identified for each species by observing the trends in survival for the whole duration of the experiment. An animal was considered to be dead when the pleopods ceased to beat and it no longer responded to mechanical stimulation.

Those salinities which caused the death of at least 50% of the animals during the period of the experiment have been termed lethal salinities. To avoid the effect of any natural death the following formula by Lance (1963) has been used in the calculation of % survival values:-

$$\text{Percent survival after exposure to various salinities for 10 days} = a_1/b_2 \times b_1/a_2 \times 100$$

Where:

$a_1$ = number of survivors in the experimental medium

$a_2$ = the number of animals initially placed in experimental medium

$b_1$ = the number of survivors in the control (acclimation medium)

$b_2$ = the number of animals initially placed in the control (acclimation medium)

## (iii) Experiments and Results

### 1.1. Tolerance of S. annandalei acclimated in 1‰ S.

After acclimation in 1‰ S, animals were placed in salinities 0 ‰ (distilled water), 0.2‰, 0.5‰, 2‰, 5‰, 10‰, 20‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰, and 70‰. Survival was 100% in salinities 5 - 20‰. The lower lethal salinity was found to be 0‰ and the higher to be 33‰ (Table 2).

### 1.2. Tolerance of S. annandalei acclimated in 17‰ S.

Animals after acclimation in 17‰ S were directly transferred to salinities 0‰, 0.5‰, 1‰, 2‰, 5‰, 10‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰, and 70‰. 100% survival was noticed in 2 - 33‰ salinities. Survival was nil in salinities 0‰ and 40 - 70‰. The lower and higher lethal salinities were found to be 0.5‰ and 40‰, respectively (Table-3).

### 1.3. Tolerance of S. annandalei acclimated in 33‰ S.

S. annandalei acclimated in 33‰ S were abruptly transferred to various media having salinities 0‰, 1‰, 2‰, 5‰, 10‰, 20‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰. Survival was 100 % in salinities 10‰

and 20‰. No one survived in salinities 0‰ and 55 - 70‰ till the end of the experiment. The lower lethal salinity was found to be 2‰ and the higher to be 45‰ (Table 4).

2.1. Tolerance of C. fluviatilis acclimated in 1‰ S.

Animals acclimated in 1‰ S were directly placed in salinities 0‰, 0.1‰, 0.2‰, 0.5‰, 2‰, 5‰, 10‰, 15‰, 20‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰. 100% survival was observed in salinities 0.2 - 33‰. Survival was nil in salinities 0‰ and 55 - 70‰ (Table-5). 0‰ and 50‰ were found to be the lower and higher lethal salinities respectively.

2.2. Tolerance of C. fluviatilis acclimated in 17‰ S.

After acclimation in 17‰ S animals were directly transferred to salinities 0‰, 0.5‰, 1‰, 2‰, 5‰, 10‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰. Survival was 100% in salinities 5 - 33‰ and nil in salinities 0‰ and 55 - 70‰ (Table-6). The lower lethal salinity was found to be 0.5‰ while the higher was found to be 50‰.

2.3. Tolerance of C. fluviatilis acclimated in 33‰ S.

Animals were directly transferred from 33‰ S to salinities 0‰, 0.5‰, 1‰, 2‰, 5‰, 10‰, 15‰, 20‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰. No mortality occurred in salinities 15‰ to 40‰. Survival was nil in salinities 0‰ and 70‰ at the end of the experiment. Survival rate varied in other salinities (Table-7). The lower

and higher lethal salinities of animals acclimated in 33‰ S were found to be 2‰ and 60‰ respectively.

3.1. Tolerance of C. willeyi acclimated in 1‰ S.

After acclimation in 1‰ S, the animals were transferred to salinities 0‰, 0.2‰, 2.5‰, 5‰, 10‰, 15‰, 20‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰. 100% survival was found in 0.2 - 33‰ salinities. No lower lethal salinity seemed to exist since 80% of the animals survived in 0‰ S, while the higher lethal salinity was found to be 40‰ (Table-8).

3.2. Tolerance of C. willeyi acclimated in 17‰ S.

Animals acclimated in 17‰ S were directly transferred to 0‰, 0.5‰, 1‰, 2‰, 5‰, 10‰, 25‰, 33‰, 40‰, 45‰, 50‰, 55‰, 60‰ and 70‰ salinities. 100% survival was noticed in 5 - 33‰ salinities. Survival was nil in 0‰ and 50 - 70‰ salinities. The respective lethal salinities were found to be 0.5‰ and 40‰ (Table-9).

3.3. Tolerance of C. willeyi acclimated in 33‰ S.

The animals after acclimation in 33‰ S were abruptly changed to 0‰, 1‰, 2‰, 5‰, 10‰, 15‰, 20‰, 25‰, 40‰, 45‰, 50‰, 55‰, 60‰, and 70‰ salinities. Survival was 100% in salinities 5 - 40‰. In 0‰ S and 55 - 70‰ S. survival was nil. The lower and higher lethal salinities were found to be 2‰ and 45‰, respectively (Table-10).

Table 2. Per cent survival of S. annandalei at time intervals(days) when transferred to different salinities after acclimation in 1‰ S.

| Days | Salinity ‰ 0 | 0.2 | 0.5 - 20 | 25 | 33 | 40 | 45-70 |
|---|---|---|---|---|---|---|---|
| 1 | 100 | 100 | 100 | 100 | 100 | 30 | 0 |
| 2 | 60 | 80 | 100 | 70 | 60 | 0 | 0 |
| 3 | 40 | 80 | 100 | 60 | 60 | 0 | 0 |
| 4 | 0 | 80 | 100 | 60 | 40 | 0 | 0 |
| 5-10 | 0 | 80 | 100 | 60 | 20 | 0 | 0 |

Table 3. Per cent survival of S.annandalei at time intervals(days) when directly transferred to various salinities after acclimation in 17‰ S.

| Days | Salinity ‰ 0 | 0.5 | 1 | 2-25 | 33 | 40 | 45 | 50-70 |
|---|---|---|---|---|---|---|---|---|
| 1 | 70 | 80 | 100 | 100 | 100 | 60 | 20 | 0 |
| 2 | 70 | 80 | 80 | 100 | 80 | 30 | 0 | 0 |
| 3 | 30 | 50 | 80 | 100 | 80 | 0 | 0 | 0 |
| 4-10 | 0 | 40 | 80 | 100 | 80 | 0 | 0 | 0 |

Table 4. Per cent survival of S. annandalei at time intervals(days) when directly transferred to various salinities after acclimation in 33‰ S.

| Days | Salinity ‰ 0-1 | 2 | 5 | 10-33 | 40 | 45 | 50 | 55-70 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 40 | 100 | 100 | 100 | 50 | 20 | 0 |
| 2 | 0 | 20 | 80 | 100 | 90 | 30 | 0 | 0 |
| 3-10 | 0 | 20 | 80 | 100 | 90 | 0 | 0 | 0 |

Table 5. Percent survival of *C. fluviatilis* at time intervals(days) when directly transferred to various salinities after accimilation in 1‰ S.

| | Salinity ‰ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Days | 0 | 0.1 | 0.2–33 | 40 | 45 | 50 | 55 | 60–70 |
| 1 | 40 | 80 | 100 | 100 | 80 | 60 | 20 | 0 |
| 2 | 40 | 80 | 100 | 80 | 60 | 60 | 0 | 0 |
| 3 | 40 | 60 | 100 | 80 | 60 | 60 | 0 | 0 |
| 4 | 40 | 60 | 100 | 80 | 60 | 60 | 0 | 0 |
| 5 | 40 | 60 | 100 | 80 | 60 | 20 | 0 | 0 |
| 6 | 40 | 60 | 100 | 80 | 60 | 20 | 0 | 0 |
| 7 | 40 | 60 | 100 | 80 | 60 | 20 | 0 | 0 |
| 8–10 | 20 | 60 | 100 | 80 | 60 | 20 | 0 | 0 |

Table 6. Per cent survival of *C. fluviatilis* at time intervals(days) when directly transferred to various salinities after acclimation in 17‰ S.

| | Salinity ‰ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Days | 0 | 0.5 | 1 | 2 | 5–33 | 40 | 45 | 50 | 55 | 60–70 |
| 1 | 10 | 40 | 60 | 80 | 100 | 100 | 100 | 90 | 50 | 0 |
| 2 | 10 | 30 | 60 | 80 | 100 | 80 | 80 | 50 | 0 | 0 |
| 3 | 0 | 30 | 60 | 70 | 100 | 80 | 70 | 50 | 0 | 0 |
| 4 | 0 | 30 | 60 | 70 | 100 | 80 | 70 | 50 | 0 | 0 |
| 5–10 | 0 | 30 | 60 | 70 | 100 | 80 | 70 | 40 | 0 | 0 |

Table 7. Per cent survival of C. fluviatilis at time intervals(days) when directly transferred to various salinities after acclimation in 33‰ S.

| | Salinity ‰ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days | 0 | 0.5 | 1 | 2 | 5 | 10 | 15–40 | 45 | 50 | 55 | 60 | 70 |
| 1 | 0 | 20 | 20 | 50 | 80 | 80 | 100 | 100 | 100 | 80 | 50 | 0 |
| 2 | 0 | 20 | 20 | 30 | 60 | 80 | 100 | 100 | 100 | 60 | 50 | 0 |
| 3 | 0 | 20 | 20 | 30 | 60 | 80 | 100 | 100 | 100 | 60 | 40 | 0 |
| 4 | 0 | 20 | 20 | 30 | 60 | 80 | 100 | 100 | 80 | 60 | 30 | 0 |
| 5–10 | 0 | 20 | 20 | 20 | 60 | 60 | 100 | 80 | 80 | 60 | 30 | 0 |

Table 8. Per cent survival of C. willeyi at time intervals(days) when directly transferred to various salinities after acclimation in 1‰ S.

| | Salinity ‰ | | | | |
|---|---|---|---|---|---|
| Days | 0 | 0.2–33 | 40 | 45 | 50–70 |
| 1 | 80 | 100 | 60 | 40 | 0 |
| 2 | 80 | 100 | 60 | 20 | 0 |
| 3–10 | 80 | 100 | 30 | 0 | 0 |

Table 9. Per cent survival of C. willeyi at time intervals(days) when directly transferred to various salinities after acclimation in 17‰ S.

| | Salinity ‰ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Days | 0 | 0.5 | 1 | 2 | 5–33 | 40 | 45 | 50–70 |
| 1 | 30 | 80 | 80 | 100 | 100 | 60 | 50 | 0 |
| 2 | 0 | 70 | 70 | 90 | 100 | 50 | 30 | 0 |
| 3–10 | 0 | 40 | 70 | 90 | 100 | 50 | 30 | 0 |

Table 10. Per cent survival of C. willeyi at time intervals (days) when directly transferred to various salinities after acclimation in 33‰ S.

| | Salinity ‰ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Days | 0 | 1 | 2 | 3 | 5–40 | 45 | 50 | 55–70 |
| 1 | 0 | 20 | 60 | 80 | 100 | 60 | 20 | 0 |
| 2 | 0 | 20 | 40 | 60 | 100 | 50 | 0 | 0 |
| 3 | 0 | 20 | 20 | 60 | 100 | 50 | 0 | 0 |
| 4–10 | 0 | 20 | 20 | 60 | 100 | 40 | 0 | 0 |

## (iv) Discussion

Assessment of salinity tolerances based only on field observations is difficult since the effects of salinity may be modified by other environmental factors (Kinne, 1971). Laboratory experiments conducted under controlled environmental conditions using acclimated specimens collected from comparable habitats give more detailed information on the response of organisms to variations in salinity. The present study supplemented by field observations shows that these three isopods are essentially euryhaline, since they inhabit estuarine regions tolerating wide ranges of salinity variations. But the ranges of salinity tolerated by each species vary depending on the salinity of the acclimation medium. Thus S. annandalei acclimated in 33‰ S tolerated salinities 5 - 40‰, C. fluviatilis 5 - 55‰ and C. willeyi 3 - 40‰ when subjected to abrupt changes. Experiments using animals acclimated in 17‰ S showed that S. annandalei survived well in salinities 1 - 33‰, C. fluviatilis in 1 - 45‰ and C. willeyi in 1 - 40‰. Animals acclimated in 1‰ S showed the following ranges of tolerence: S. annandalei 0.2 - 25‰ S, C. fluviatilis 0.1 - 45‰ S and C. willeyi 0 - 33‰ S.

Remane (1958) classified euryhaline animals into four groups based on the lowest salinities to which they penetrate. The first group of animals includes those which penetrate to a salinity of 15‰. The second group penetrates to 15 - 8‰ salinities and the third group is capable of penetrating to salinities between 8‰ and 3‰. The fourth grade of euryhaline marine animals penetrate to salinities below 3‰. According to the above classification these isopods can be included in

the fourth group. Animals which can exist in fresh, brackish and sea water have been called as 'holeuryhaline' species (Kinne, 1971). Even though these isopods are found to tolerate the above conditions, it is doubtful whether they can be called holeuryhaline since they do not inhabit the sea or fresh water usually. However, C. fluviatilis has been observed in the sea also.

It has been found that in general, acclimation to low salinities tends to shift the lower lethal limit downward and acclimation to higher salinities tends to shift the upper limit upward (Kinne, 1964). This generalisation is in agreement with the present findings fully in the case of S. annandalei only. In the others even though there is a shift in the lower limits (100% mortality) downward in accordance with the decrease in the acclimation salinity, the upper limits do not show a corresponding increase with the increase in the acclimation salinity. Thus C. fluviatilis shows the same upper limit of 45‰S for both 1‰ and and 17‰ salinities of the acclimation medium. On the other hand C. willeyi has the same upper lethal limit of 40‰ for both acclimated in 17‰ and 33‰ salinities (Table 5, 6, 9, 10). Except for the upper limits of both these species acclimated in 17‰S, the generalisation of Kinne (1964) is applicable in the present findings. When the lethal salinities (50% mortality) are taken into consideration also, only S. annandalei agrees with the above generalisation. The upper lethal salinities of C. fluviatilis and C. willeyi remained the same in spite of the increase in the acclimation salinity from 1‰ to 17‰. However, there is a marked increase in the number of survivors in the upper lethal salinities of

C. fluviatilis and C. willeyi corresponding with the increase from 1‰ to 17‰ in the acclimation salinity.

Nagabhushanam and Gopalakrishanamurthy (1965) studied the salinity tolerance of C. fluviatilis from the Visakhapatnam harbour in the East Coast of India, and found that the lethal salinity appeared to lie between 4 and 5‰. This range is high compared to the present finding. However, this difference seems to be of not much significance since in both cases the lethal limit falls between 2 - 5‰ S. But the validity of taking this range of the salinity as the lethal limit of C. fluviatilis is doubtful since their finding is based on experiments using animals acclimated in 30‰ S only. Moreover, the present study has revealed that this species thrives even during fresh water conditions as evidenced by field observations and laboratory experiments using animals acclimated in low salinities.

Pillai (1961) observed that all the three species occur in estuarine regions in the East and West Coasts of India. According to him S. annandalei is abundant in the estuaries and are also found far away from the barmouth. He also observed that they are fairly common in the open sea. These observations lead to the assumption that S. annandalei is capable of living in the sea as well as in the remote regions of the estuaries where the salinity is very low. But during the present investigation specimens of S. annandalei could neither be obtained nor their presence noted from the open sea or the immediate vicinity of the barmouth. Instead they were found to be abundant in the remote regions of the estuary

and in the canals and paddy fields connected to it. The salinity of these regions is very low during most part of the year. The laboratory experiments also reveal that they prefer low salinities. Even animals acclimated in 33‰ S did not survive beyond 40‰ S, while C. fluviatilis and C. willeyi showed better tolerance. Even though its survival was poor in very low salinities when subjected to abrupt changes from acclimation medium of higher salinities, field observations reveal that S. annandalei can exist in near fresh water conditions. Based on these findings it can be assumed that S. annandalei is essentially a brackish water species which prefers low salinities and the degree of euryhalinity exhibited by it is less compared to those of the other two isopods.

Survival of C. willeyi also, in supranormal salinities is poor compared with C. fluviatilis. But they showed better tolerance in salinities near to that of fresh water and there was 80% survival in 0‰ S when animals acclimated in 1‰ S were subjected to abrupt change. These observations are evidences for the inclination of this euryhaline species to very low salinities.

Based on the rate of survival in the experimental media, it can be concluded that C. fluviatilis is the most tolerant of the three species of isopods. Animals acclimated in 33‰ S tolerated supranormal salinities as high as 55‰, while those acclimated in 1‰ S survived well even in 0.1‰ S. However, they did not survive in 0‰ S. But the high rate of survival in 0.1‰ S accounts for their ability to tolerate

fresh water conditions.

A comparative study of the effects of salinity on the two species of Cirolana suggests that C. willeyi is able to tolerate fresh water conditions more effectively than C. fluviatilis. But it has been pointed out by Gunter (1956) that the lower salinity limits for estuarine species cannot be sharply defined. Pearse and Gunter (1957) have stressed that once an animal has adjusted to salinity changes, its range of tolerance may exceed the usual environmental changes, so that it could survive unusual conditions. But Bassindale (1943) is of opinion that salinity tolerance indicated by laboratory experiments may be greater than is implied by the distribution of animals in an estuary, where daily variations in salinity can have a cumulative effect, restricting the animals to higher salinities. This accounts for the fact that even though C. willeyi is capable of tolerating even 0‰ S as observed in the laboratory, they are not usually found in purely fresh water areas. However, considering the concept that brackish waters are inhabited by species evolved from closely related marine or fresh water ancestors, there are reasons to believe that C. willeyi and C. fluviatilis are more of a marine origin, since they have been found to thrive in the region during the summer season, January to May when the salinity is around 33‰. But the ability of C. willeyi to tolerate very low salinities more effectively than C. fluviatilis suggests that the former is a xxxxx step ahead of the latter in conquering the realm of fresh water and it is significant in a study of the evolutionary origin of the fresh water fauna.

IV

# STUDIES ON OXYGEN CONSUMPTION

## (i) Introduction

The performances of estuarine animals within the range of sublethal salinity conditions may be modified in various ways and these variations are of great importance in the distribution and population dynamics of these organisms. The modifying effect of salinity on the metabolism is one of the intensively studied aspects in this field. The environmental factors which affect metabolic rate have been catagorised into two: controlling factors and limiting factors (Blackman, 1905; Fry, 1947; Newell, 1970). The controlling factors in which several factors may operate simultaneously governing both the maximal and minimal metabolic rates include salinity and temperature, while the limiting factors are those which actually enter into the chain of metabolic processes of the organism and include the availability of oxygen and substrate supply. Salinity which is the environmental master factor in a tropical estuary and availability of oxygen which is the most important limiting factor in the environment are the two parameters investigated in the present study to know their influence on the metabolism of the three isopods.

Besides these environmental factors the metabolism is influenced by certain endogenous factors, the most important of them being the body size of the organism concerned and the level of its activity. Obviously the influence of these 'intrinsic factors' (Vernberg and Vernberg, 1972)

must be eliminated before other factors can be effectively studied. Hence a study of the metabolic rate in relation to environmental factors like salinity and oxygen concentration is possible only after understanding the effects of these endogenous factors mainly body size. The influence of body size on the metabolism has been studied by Kleiber (1932, 1947), Brody and Procter (1932), Brody (1945), Zeuthen (1947, 1953), Hemmingsen (1950, 1960) and Bertalanffy (1957). In recent years a vast body of information on the relation between metabolic rate and body size of poikilotherms has been added to the above works and detailed reviews on this aspect are available in the works of Wolvekamp and Waterman (1960), Prosser and Brown (1961), Lockwood (1967) and Newell (1970).

In general, metabolism is proportional to a constant power of the body weight (Zeuthen, 1947, 1953; Hemmingsen, 1950, 1960). This relation between the metabolism of the whole animal and body weight is expressed as:

$$O_2 = aw^b$$

where '$O_2$' is the total oxygen consumed in unit time; 'w' is the body weight and 'a' and 'b' are constants. In its logarithmic form the equation becomes:

$$\log O_2 = \log a + b \log w$$

when plotted, a straight line rather than an exponential curve is obtained relating metabolism to body weight.

Considering the apparently fundamental relationship between metabolism and body weight several attempts have been made to explain the mechanism underlying the phenomenon. Zeuthen (1953) suggested that the metabolism of metazoans would be related to their aggregate cell surface and expected the metabolism to increase with the $\frac{2}{3}$ or 0.67 power of body weight. According to Hemmingsen (1950, 1960) metabolism is proportional, not to the cell surface itself, but to factors like internal convection, vascularisation and the development of complex respiratory systems. He showed that metabolism varies more nearly with the $\frac{3}{4}$ or 0.751 power of the body weight. Bertalanffy (1957) reviewing the relationship between body size and metabolism distinguished three types: proportionality of metabolic rate to surface area or to weight; intermediate between surface and weight and intermediate between surface and weight proportionality.

Even though the metabolism of large animals exceeds that of small animals, it does not increase at the same rate as body weight. Thus weight specific metabolism expressed as oxygen consumed per unit time of small animals is greater than that of large ones. From the equation $O_2 = aw^b$, the weight specific metabolic rate can be expressed as:

$$\frac{O_2}{w} = aw^{(b-1)}$$

Since 'b' is usually less than 1.0, b-1 has a negative value showing a decline with increase in body weight which can be expressed as:

$$\text{Log } \frac{O_2}{w} = \log a + (b-1) \log w$$

This negative exponential relationship between metabolic rate and body weight has been established by Zeuthen (1947) for a wide variety of organisms. But since the nature of this relationship varies even within one species, interpretations of the size correlations of metabolism has been difficult as pointed out by Prosser and Brown (1961).

As has been mentioned earlier salinity is the most important environmental factor affecting life in a tropical estuary. The fact that salinity variations may modify the metabolic rate of aquatic invertebrates has been established by a considerable number of papers on the basis of experiments on oxygen consumption. Yet, as Kinne (1964) observed we still do not possess a satisfactory body of knowledge on this aspect. Studies on short term and long term responses of stabilized animals to salinity changes with respect to the past and present environmental histories of the organism concerned are relatively few. Further, evaluation of the effects of salinity on oxygen consumption is complicated by the fact that oxygen content of the water itself depends on salinity besides other factors. As the oxygen content is a limiting factor in the metabolism of animals it is often difficult to determine the responses due to salinity alone as has been pointed out by Kinne (1964). In brief, the relation between salinity and oxygen consumption in marine invertebrates is not very clear. Wolvekamp and Waterman (1960) in their review conclude that 'in some organisms respiration varies inversely with salinity, while in others there appears to be no correlation'.

In Crustacea, the oxygen consumption in relation to salinity has been investigated by many workers. Reviews on the effect of salinity on metabolism are available in the works of Wolvekamp and Waterman (1960), Lockwood (1967), Newell (1970), Kinne (1971) and Vernberg and Vernberg (1972).

Even though a critical assessment of the effects of salinity on oxygen consumption has been difficult, Kinne (1966, 1971) has found certain general trends in the modifications of metabolic rate in relation to salinity changes. According to him within sublethal ranges of salinity variations the respiratory rate of marine and brackish water invertebrates may (i) increase in subnormal salinities and/or decrease in supranormal salinities, (ii) increase in sub-and supranormal salinities, (iii) decrease in sub- and supranormal salinities, (iv) remain essentially unaffected. He also observed that the first two types are represented largely by euryhaline forms, the third by stenohaline forms and the fourth by extremely euryhaline or holeuryhalaine forms (also, Vernberg and Vernberg, 1972).

The modifying effects of salinity changes on respiratory rates have also been shown to depend on temperature, body size and oxygen concentration as revealed by the studies by Dehnel (1960) on Hemigrapsus oregonensis and H. nudus. Eliassen (1953) and Rao (1958) have shown that in Artemia salina and Metapenaeus monoceros respectively, differences in oxygen consumption are more pronounced in smaller specimens than in larger ones, when subjected to salinity changes. Hence a study

on the influence of body size and oxygen concentration in salinity-induced changes in the respiratory rates was also included in the present investigation. Effects of varying temperature were not attempted in the present study since considerable variations in temperature do not occur in the habitat as has been mentioned in Chapter III.

Based on the available information on the relationship between salinity and metabolism, Kinne (1971) arrived at two generalisations: "(i) many aquatic invertebrates respire at most economic rates in salinities to which they have been acclimated over prolonged periods of time, (ii) respiratory demands due to salinity stress can be reduced by beneficial intensities of other concomitantly effective environmental factors (possibly also by reductions in muscular activity)".

Potts and Parry (1964) have critically discussed the relationship between salinity stress and respiratory rates. The hypothesis that the increase in respiratory rate in subnormal salinities is due to increased energy demands for active ion transport is not accepted by them on the grounds that (i) changes in metabolic rate are generally more pronounced than caused by the energy requirements of active ion transport, (ii) in several cases, the increased metabolic rate is not confined to the tissues which perform osmotic work, (iii) the pronounced changes in metabolic rate imply low efficiencies of the transport of ions whereas excised tissues show high efficiencies, (iv) there are instances of metabolic rate being lower in subnormal salinities, higher in supranormal salinities or unaffected.

Gross (1957), McFarland and Pickens (1965) and Duncan and Klekowski (1967) have shown that salinity changes can affect metabolic rates by stimulation or diminution of locomotion. Salinity may influence metabolic rate also by increase or decrease of the concentration of body fluid, by changes in internal ion ratios and by interference with neuromuscular, hormonal or enzymatic mechanisms (Kinne, 1971). In brief it appears that the influence of salinity on metabolic rates cannot be accounted for by any single hypothesis and that studies on this aspect on more and more species of animals may reveal new insights of the problem, widening the limits of the present body of information.

The role of dissolved oxygen as a limiting factor in the respiratory metabolism is of vital importance in the ecology of estuarine animals. Blackman (1905) defining the concept of limiting factors stressed that "when a process is limited as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor". The amount of dissolved oxygen may vary markedly in different habitats or in the same habitat at different times. Sometimes the habitat may be supersaturated with oxygen while at times it may be more or less anaerobic. Marine organisms show varying degrees of dependence on dissolved oxygen according to the physiological capacity and ecological requirements of the organisms. Some animals require high concentrations of oxygen in the environment while some others are able to survive in anaerobic conditions. Estuarine animals are subjected to varying concentrations of oxygen which may fluctuate as a function of time.

Henze (1910) generalised the relation between oxygen concentration and respiration stating that the respiration of simpler, bulkier invertebrates is oxygen dependent while it is independent in higher invertebrates. Later von Ledebuhr (1939) showed that marine animals can withstand large variations of oxygen tension and that variations in respiratory rate are exhibited only at low levels. The influence of oxygen tension on respiratory rate has received much attention in the last few decades and our knowledge on this aspect has increased much. Consequently many exceptions to the above generalisations have been demonstrated by several workers.

Reviews on the metabolic responses to oxygen tension are available in the works of Tang (1933), Krogh (1941), von Brand (1945), Zeuthen (1955), Wolvekamp and Waterman (1960), Prosser and Brown (1961), Lockwood (1967), Newell (1970), Vernberg (1972) and Vernberg and Vernberg (1972). Two categories of responses to varying oxygen tension - one oxygen dependent and the other oxygen independent - have been noticed in marine animals (Lockwood, 1967; Vernberg, 1972). In the oxygen dependent category, the oxygen consumption of the animal is directly proportional to the oxygen tension of the medium. Species in which respiration is thus limited by the amount of oxygen present in the surrounding medium are called 'conformers'. In the oxygen-independent category the rate of respiration remains unaffected until some critical oxygen tension is reached. Below this critical tension the respiratory rate becomes dependent on the availability of oxygen as in the conformers. Animals belonging to this category are called 'regulators' (Lockwood, 1967).

As has been mentioned earlier the mode of oxygen consumption of marine organisms is influenced by not a single factor alone. All the endogenous and environmental factors interact to produce wide variations in the respiratory rate. Hence an evaluation of the combined effects of the parameters selected for the present study on the respiratory metabolism of the three species of isopods has also been attempted.

In brief, as it is revealed in the information presented above there exists a great diversity in regard to the effects of factors influencing the respiratory metabolism of aquatic animals. Generalisations of the various physiological mechanisms evolved by these animals to adjust themselves to the varying environmental conditions are not possible based only on our present knowledge on these aspects, as has been pointed out by Vernberg (1972). A great deal more has to be studied to make possible a thorough analysis of the mechanisms of physiological adjustments to environmental stress. The present studies are aimed at providing some information on such aspects of the three species of economically important isopods.

## (ii) Materials and Methods

Respiratory rate is the most widely used parameter in studies on metabolism and a variety of methods have been employed in measuring the oxygen consumption. Recently Cheriyan (1973) described a method which was found quite suitable for respiratory measurements of small aquatic organisms like isopods and it was used for the present studies

PLATE 4

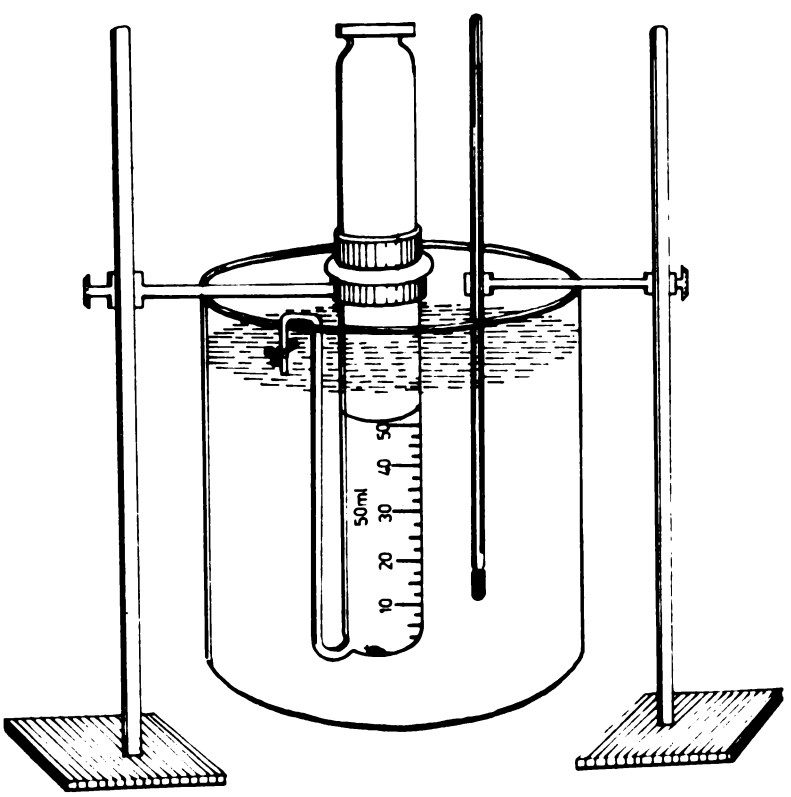



FIG 6 Respiratory Apparatus

(Fig.6). The respiratory chamber of the apparatus is a graduated 50 ml glass syringe with the piston. The nozzle of the respiratory chamber is connected to a narrow rubber tube provided with a pinch-cock and is used for filling the chamber and taking water samples out, moving the piston. The respiratory chamber is kept in water in a glass trough vertically with the aid of a stand as shown in the figure. The piston is provided with a movable rubber catch which rests upon the rim of the respiratory chamber in the set position and prevents any pressure exerted on the water inside the chamber by the piston. The catch can be released enabling the movement of the piston as and when required. The water in the trough is connected to an electrically heated water bath to maintain the temperature at the required level. A thermometer is also kept in position in the trough by means of a stand.

The respiratory chamber is filled with water of the desired salinity and oxygen tension. After introducing the animal inside the chamber and taking an initial water sample of 10 ml, the piston is set at the 50 ml mark. Five water samples of 10 ml each are collected at suitable intervals under declining oxygen tension during an experiment.

The oxygen in the water samples is estimated using Winkler's micromethod as described by Welsh and Smith (1953). A burette with the accuracy of 0.005 ml is used for the titration.

In the laboratory it was observed that the three isopods under study are capable of maintaining a powerful water current by the beating of the pleopods. This ability of isopods to produce a stream of water

by pleopod movements has also been reported by Omer-Cooper and Rawson (1934). Wieser (1962) found that the movements of the pleopods was sufficient to ensure a rapid diffusion of gases in the water and hence the respirometer was not shaken in his experiments on isopod respiration. During the present study also ~~it~~ by running trial experiments using stains it was observed that the circulation of water inside the 50 ml capacity respiratory chamber, caused by the pleopod movements of the animal was sufficient to ensure rapid mixing. This was further verified by running experiments and analysing water samples for oxygen, collected from different levels of the respiratory chamber at one time. Therefore no additional effort was made to ensure mixing.

Collection and acclimatisation of the animals were done as described in Chapter III. Experiments were carried out using animals acclimated in salinities 1‰, 17‰ and 33‰, representing the three hydrographical seasons prevailing in the natural habitat.

The animals selected for the experiments were transferred from the aquarium tanks, washed with filtered and aerated water of the acclimation salinity and kept in glass troughs containing filtered and aerated water of the same salinity in darkness and without food for 24 hours before they were used for experiments.

The apparatus was set as described earlier. One animal each was used at a time in each respiratory chamber. The animal was allowed to remain in the respiratory chamber in the acclimation salinity for two hours before each experiment was started in order to get it accustomed to the new surrounding. They were not fed and kept in darkness during

the experiments. In most cases 18 animals of different weights were tested in each medium. But in a few cases the number varied.

The first series of experiments were conducted to find out the rate of oxygen consumption in the three acclimation salinities of 1‰, 17‰ and 33‰. In the second series animals were directly transferred from the acclimation salinity to the other two salinities. Thus animals acclimated in 1‰S were directly transferred to 17‰S and 33‰S; those acclimated in 17‰S were transferred to 1‰S and 33‰S and those from 33‰S were changed to 17‰S and 1‰S.

Water samples for $O_2$ were collected at suitable intervals till the death of the animal to study the respiratory rate under depleting oxygen tension to the lethal level. The animal was deemed dead when the pleopod beating ceased and the body turned upside down. Wet weight of the animal was taken at the end of each experiment after carefully wiping it between folds of blotting paper. The weight was recorded to the nearest 0.1 mg and it varied from 7.2 to 66.5 mg in S. annandalei and from 7.7 to 40.5 mg in Cirolana spp.

Since these animals spend much of their time in hiding places or burrows, locomotor activity is at the minimum in the natural environment. In the respiratory chamber also, the animals take shelter in the excavation present at the bottom, at the junction of the outlet and swimming activity was not generally observed. Thus inside the respiratory chamber the individual isopod was routinely active (McLeese, 1964) and hence the rate of oxygen consumption of these isopods can be related to

the routine rate.

The series of experiments carried out are the following:-

1. Oxygen consumption in relation to body weight in acclimation salinities.

2. Oxygen consumption in relation to body weight in varying salinities

3. Oxygen consumption in relation to body weight in declining oxygen tension in acclimation salinities and in varying salinities.

4. Lethal level of oxygen concentration

The numerical data thus obtained were statistically analysed using the models:-

$$(i)\ O_2 = aw^b \quad \text{and} \quad \frac{O_2}{w} = aw^{b-1}$$

The parameters 'a' and 'b' were estimated by the method of least square after converting the model into linear forms by taking the logarithms of $O_2$ and w, i.e.,

$$(i)\ \log O_2 = \log a + b \log w \quad \text{and}$$

$$(ii)\ \log O_2 - \log w = \log a + b \log w - \log w$$

The calculations were done taking upto 7 decimals. But the values corrected to 4 decimals are shown in the tables presented.

## (iii) Experiments and Results

### 1.1. Oxygen consumption of S. annandalei in relation to body weight in the acclimation salinities

Oxygen consumption of S. annandalei in relation to body weight was studied in three acclimation media of salinities 1‰, 17‰ and 33‰.

#### (a) Oxygen consumption in the acclimation medium of 1‰ S:

Data obtained on the oxygen consumption of S. annandalei in the acclimation salinity of 1‰ in $pO_2$ (partial pressure of oxygen) 140 mm Hg are presented in Table 11. The oxygen uptake per unit time showed an increasing tendency with increasing body weight and hence the data were analysed using the formula $O_2 = aw^b$. The regression coefficient 'b' of the $O_2$ uptake against body weight was obtained as 0.3423 and the parameter 'a' as 0.5151. The line is plotted in Fig.7 which shows a high positive linear relationship.

The metabolic rate in terms of $O_2$ uptake per unit weight in unit time ($O_2$µl/g/h) given by the formula $\frac{O_2}{w} = aw^{b-1}$ showed a decline with the increasing body weight resulting in a negative linear relationship (Fig.8). The regression value for the weight specific oxygen consumption (metabolic rate) which is b-1 in the above formula was obtained as - 0.6577.

#### (b) Oxygen consumption in the acclimation medium of 17‰ S:

The results of the experiments in the acclimation medium of 17‰ S in $pO_2$ 140 mm Hg are given in Table 12. Figures 9 and 10

illustrate the relationship obtained between $O_2$ uptake, metabolic rate and body weight. The estimates of 'b' and 'a' were obtained as 0.4457 and 0.3360, respectively. The regression value for metabolic rate against body weight ('b-1') was obtained as - 0.5543.

(c) Oxygen consumption in the acclimation medium of 33‰ S:

Table 13 shows the respiratory rates obtained in the acclimation medium of 33‰ S. The relationships of oxygen uptake and metabolic rate to body weight are illustrated in Figs. 11 and 12. The values of 'b', 'a' and 'b-1' were 0.4854, 0.3361 and - 0.5146, respectively.

The results of the statistical analysis of the data obtained on the oxygen consumption in the above three acclimation salinities are presented in Table 14. Statistically refined values for $O_2$ uptake and metabolic rate of animals of standard weights 10, 20, 30, 40, 50 and 60 mg in the acclimation media in $pO_2$ 140 mm Hg are given in Table 15.

The regression coefficients obtained in the three acclimation media were compared and the results are shown in Table 16.

1.2. Oxygen consumption of S. annandalei in relation to variations in salinity and body weight:

Animals were directly transferred from the acclimation medium to higher and lower salinities and their respiratory rates were studied.

(a) Oxygen consumption when transferred from the acclimation medium of 1‰ S to 17‰ S:

The respiratory rates of S. annandalei transferred to 17‰ S from the acclimation medium of 1‰ S are given in Table 17. The regression line is given in Figure 13. The values of 'a', 'b' and 'b-1' were obtained as 0.2975, 0.5008 and - 0.4992, respectively.

(b) Oxygen consumption when transferred from the acclimation medium of 1‰ S to 33‰ S:

Data obtained are presented in Table 18. The regression line is shown in Fig. 13. The estimates of 'a', 'b' and 'b-1' were 0.0833, 0.4979 and - 0.5021, respectively.

(c) Oxygen consumption when transferred from the acclimation medium of 17‰ S to 1‰ S:

Animals acclimated in 17‰ S were directly transferred to 1‰ S and the data obtained on the oxygen consumption in $pO_2$ 140 mm Hg are presented in Table 19. The relationship between body weight and $O_2$ uptake is shown in Fig. 14. The values of 'a', 'b' and 'b-1' were found to be - 0.0608, 0.6430 and - 0.3570, respectively.

(d) Oxygen consumption when transferred from the acclimation medium of 33‰ S to 17‰ S:

The results of the experiments are presented in Table 20 and Fig. 15. The values of 'a', 'b' and 'b-1' were obtained as 0.4113, 0.4933 and - 0.5067, respectively.

Statistically refined values for $O_2$ uptake and metabolic rates of standard weights 10, 20, 30, 40, 50 and 60 mg when subjected to salinity variations are given in Table 21. (Ref. Table 15 for the standard rates in the acclimation media.)

Results of the statistical analysis of the data on oxygen consumption when subjected to variations in salinity are presented in Table 22.

The regression coefficients obtained under variations in salinity were compared and the results are shown in Table 23.

1.3. Oxygen consumption of S. annandalei in relation to body weight and declining oxygen tension in the acclimation media

Oxygen consumption in relation to body weight of animals in the acclimation media of 1, 17 and 33‰ S under declining partial pressure of dissolved oxygen ($pO_2$) was studied.

(a) Oxygen consumption in declining $pO_2$ in the acclimation medium of 1‰ S:

The regression lines obtained under declining partial pressure of oxygen ($pO_2$) in the acclimation medium of 1‰ S are shown in Fig.16. The values of 'b' obtained in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.3423, 0.3423, 0.3423, 0.4333, 0.3492 and 0.2410, respectively. Respiratory rates for standard weights 10, 20, 30, 40, 50 and 60 mg in $pO_2$ 120 - 40 mm Hg are given in Table 24. (Ref. Table 15 for $O_2$ uptake in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $pO_2$ in the acclimation medium of 17‰ S:

The relationship between $O_2$ uptake and body weight of animals in the acclimation salinity of 17‰ under declining $pO_2$ are shown in Fig.17. The 'b' values in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were obtained as 0.4457, 0.4457, 0.4457, 0.6131, 0.6811 and 0.5545, respectively. Respiratory rates for standard weights 10, 20, 30, 40, 50 and 60 mg in $pO_2$ 120 - 40 mm Hg are presented in Table 25. (Ref. Table 15 for respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ in the acclimation medium of 33‰ S:

The regression lines obtained under declining $pO_2$ in the acclimation medium of 33‰ S are shown in Fig. 18. The estimates of 'b' were 0.4854, 0.4854, 0.4854, 0.5656, 0.6556 and 0.7540 respectively under $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. Respiratory rates for standard weights 10, 20, 30, 40, 50 and 60 mg in $pO_2$ 120 - 40 mm Hg. are given in Table 26. (Ref. Table 15 for respiratory rates in $pO_2$ 140 mm Hg.)

The 'b' values and their standard errors are given in Table 27. The values were compared for their significance in the declining $O_2$ tension in the acclimation salinities and the results are presented in Table 28.

1.4. Oxygen consumption of S. annandalei in relation to body weight and salinity variations in declining oxygen tension

Specimens of S. annandalei were directly transferred from the acclimation media to media of higher and lower salinities and their

respiratory rates under declining $O_2$ tension were studied.

(a) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 17‰ S:

The regression lines for oxygen consumption against body weight obtained for animals transferred to 17‰ S from the acclimation medium of 1‰ S in declining $pO_2$ are shown in Fig. 19. The values of 'b' obtained for $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.5008, 0.5008, 0.7334, 0.7473, 0.9250 and 0.9471, respectively. The respiratory rates for standard weights in $pO_2$ 120 - 40 mm Hg are presented in Table 29. (Ref. Table 21 for respiratory rates in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 33‰ S:

The regression lines obtained for animals transferred to 33‰ S from the acclimation medium of 1‰ S are shown in Fig. 20. The estimates of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.4979, 0.4979, 0.4424, 0.4498, 0.6098 and 0.5354, respectively. The respiratory rates for standard weights 10, 20, 30, 40, 50 and 60 mg in $pO_2$ 120 - 40 mm Hg are given in Table 30. (Ref. Table 21 for respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 17‰ S to 1‰ S:

Fig. 21 shows the regression lines obtained under declining $pO_2$ for animals transferred from the acclimation medium of 17‰ S to 1‰ S.

The 'b' values obtained were 0.6430, 0.6430, 0.7204, 0.7328, 0.8507 and 0.8830 respectively in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. The $O_2$ uptake and metabolic rates for standard weights 10, 20, 30, 40, 50 and 60 mg in $pO_2$ 120 - 40 mm Hg are given in Table 31. (Ref. Table 21 for respiratory rates in $pO_2$ 140 mm Hg.)

(d) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 33‰ S to 17‰ S:

The regression lines for oxygen consumption against body weight, in declining $pO_2$ obtained for animals transferred to 17‰ S from the acclimation medium of 33‰ S are shown in Fig. 22. The values of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.4933, 0.4778, 0.4308, 0.3975, 0.3589 and 0.3458, respectively. Respiratory rates for standard weights 10, 20, 30, 40, 50 and 60 mg at $pO_2$ 120 - 40 mm Hg are given in Table 32. (Ref. Table 21 for respiratory rates in $pO_2$ 140 mm Hg.)

The regression coefficients and their standard errors are shown in Table 33.

The values were compared and the results are presented in Table 34.

2.1. Oxygen consumption of *C. fluviatilis* in relation to body weight in the acclimation salinities

Oxygen consumption of *C. fluviatilis* in relation to body weight was studied in three acclimation media of salinities 1‰, 17‰ and 33‰.

(a) Oxygen consumption in the acclimation medium of 1‰ S:

The results of the experiments are presented in Table 35. The relationships obtained between $O_2$ uptake, metabolic rate and body weight in $pO_2$ 140 mm Hg are illustrated in Figs. 23 and 24. The estimates of 'a' and 'b' were obtained as 0.9723, and 0.2495, respectively. The regression value for metabolic rate against body weight ('b-1') was found to be - 0.7505.

(b) Oxygen consumption in the acclimation medium of 17‰ S:

The data obtained on the oxygen consumption in the acclimation salinity of 17‰ in $pO_2$ 140 mm Hg are presented in Table 36. The regression lines of $O_2$ uptake and metabolic rate against body weight are shown in Figs. 25 and 26. The values of 'a', 'b' and 'b-1' were obtained as - 0.4300, 0.9173 and - 0.0827, respectively.

(c) Oxygen consumption in the acclimation medium of 33‰ S:

Table 37 shows the respiratory rates obtained in the acclimation salinity of 33‰. The relationships of oxygen uptake and metabolic rate to body weight are illustrated in Figs. 27 and 28. The estimates of 'a', 'b' and 'b-1' were 0.4839, 0.3663 and - 0.6337, respectively.

The date obtained on the oxygen consumption in the above three acclimation salinities were statistically analysed and the results are given in Table 38. Statistically refined values for $O_2$ uptake and metabolic rate of animals of standard weights 10, 20 and 30 mg in the acclimation salinities in $pO_2$ 140 mm Hg are presented in Table 39.

The regression coefficients obtained in the three acclimation media were compared and the results are given in Table 40.

2.2 Oxygen consumption of C. fluviatilis in relation to variations in salinity and body weight

Animals were directly transferred from the acclimation medium to higher and lower salinities and their respiratory rates were studied.

(a) Oxygen consumption when transferred from the acclimation medium of 1‰S to 17‰S:

The respiratory rates of C. fluviatilis transferred to 17‰S from 1‰S are given in Table 41. The relationship between $O_2$ uptake and body weight is illustrated in Fig. 29. The values of 'a', 'b' and 'b-1' were obtained as 0.3602, 0.5491 and - 0.4509, respectively.

(b) Oxygen consumption when transferred from the acclimation medium of 1‰S to 33‰S:

The results of the experiments are given in Table 42. The regression line of $O_2$ uptake against body weight is shown in Fig. 29. The estimates of 'a', 'b' and 'b-1' were 0.3595, 0.5113, and - 0.4887, respectively.

(c) Oxygen consumption when transferred from the acclimation medium of 17‰S to 1‰S:

The data obtained on the oxygen consumption in $pO_2$ 140 mm Hg are presented in Table 43. The relationship between $O_2$ uptake and body weight is shown in Fig. 30. The values of 'a', 'b' and 'b-1' were

found to be 0.3055, 0.6636 and - 0.3364, respectively.

(d) Oxygen consumption when transferred from the acclimation medium of 17‰ S to 33‰ S:

The results of the experiments are presented in Table 44 and the relationship between body weight and $O_2$ uptake is shown in Fig. 30. The estimates were 0.5236, 0.3067 and - 0.6933, respectively for 'a', 'b' and 'b-1'.

(e) Oxygen consumption when transferred from the acclimation medium of 33‰ S to 1‰ S:

Specimens acclimated in 33‰ S were directly transferred to 1‰ S and the results of the experiments in $pO_2$ 140 mm Hg are presented in Table 45. The regression line of $O_2$ uptake against body weight is shown in Fig. 31. The values of 'a', 'b' and 'b-1' were obtained as 0.0462, 0.5918 and - 0.4082, respectively.

(f) Oxygen consumption when transferred from the acclimation medium of 33‰ S to 17‰ S:

The respiratory rates of animals acclimated in 33‰ S when transferred to 17‰ S in $pO_2$ 140 mm Hg are given in Table 46 and the relationship between $O_2$ uptake and body weight is shown in Fig. 31. The estimates of 'a', 'b' and 'b-1' were 0.5255, 0.3594 and - 0.6406, respectively.

Statistically refined values for $O_2$ uptake and metabolic rates of C. fluviatilis of standard weights 10, 20 and 30 mg when subjected to salinity changes in $pO_2$ 140 mm Hg are presented in Table 47. (Ref.

(a) Oxygen consumption when transferred from the acclimation medium of 1‰ S to 17‰ S:

The respiratory rates of C. willeyi transferred to 17‰ S from 1‰ S are given in Table 69. The relationship between $O_2$ uptake and body weight is shown in Fig. 47. The values of 'a', 'b' and 'b-1' were obtained as 0.2257, 0.5867 and - 0.4133, respectively.

(b) Oxygen consumption when transferred from the acclimation medium of 1‰ S to 33‰ S:

The data obtained are presented in Table 70 and the regression line of $O_2$ uptake against body weight is shown in Fig. 47. The estimates of 'a', 'b' and 'b-1' were 0.2241, 0.6150 and - 0.3850, respectively.

(c) Oxygen consumption when transferred from the acclimation medium of 17‰ S to 1‰ S:

Animals acclimated in 17‰ S were directly transferred to 1‰ S and the data obtained on the oxygen consumption in $pO_2$ 140 mm Hg are presented in Table 71. The relationship between $O_2$ uptake and body weight is shown in Fig. 48. The values of 'a', 'b' and 'b-1' were obtained as 0.0025, 0.7828 and - 0.2172, respectively.

(d) Oxygen consumption when transferred from the acclimation medium of 17‰ S to 33‰ S:

The results of the experiments are presented in Table 72 and

the relationship between body weight and $O_2$ uptake is shown in Fig. 48. The estimates were 0.4799, 0.4158 and - 0.5842 respectively for 'a', 'b' and 'b-1'.

(e) Oxygen consumption when transferred from the acclimation medium of 33‰ S to 1‰ S:

C. willeyi acclimated in 33‰ S were directly transferred to 1‰ S and the results of the experiments in $pO_2$ 140 mm Hg are given in Table 73. The regression line of $O_2$ uptake against body weight is shown in Fig. 49. The values of 'a', 'b' and 'b-1' were obtained as 0.0521, 0.7437 and - 0.2563, respectively.

(f) Oxygen consumption when transferred from the acclimation medium of 33‰ S to 17‰ S:

The respiratory rates of animals acclimated in 33‰ S when transferred to 17‰ S in $pO_2$ 140 mm Hg are given in Table 74 and the relationship between body weight and $O_2$ uptake is shown in Fig. 49. The estimates of 'a', 'b' and 'b-1' were 0.4869, 0.4629 and - 0.5371, respectively.

Statistically refined values for $O_2$ uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg are given in Table 75. (Ref. Table 67 for standard rates in the acclimation salinities).

Results of the statistical analysis of the data obtained under variations in salinity are shown in Table 76.

The regression coefficients of $O_2$ uptake against body weight in varying salinities were compared and the results are given in Table 77.

3.3. Oxygen consumption of C. willeyi in relation to body weight and declining oxygen tension in the acclimation media:

Oxygen consumption in relation to body weight of C. willeyi in the acclimation media of 1, 17 and 33‰ S in declining partial pressure of oxygen ($pO_2$) was studied.

(a) Oxygen consumption in declining $pO_2$ in the acclimation medium of 1‰ S:

The regression lines obtained under declining $pO_2$ in the acclimation salinity of 1‰ are shown in Fig. 50. The values of 'b' obtained in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.5976, 0.6283, 0.5466, 0.4767, 0.5648 and 0.4853, respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 78. (Ref. Table 67 for respiratory rates in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $pO_2$ in the acclimation medium of 17‰ S:

The relationships between body weight and respiration of animals

in the acclimation medium of 17‰ S in declining oxygen tension are illustrated in Fig. 51. The values of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were obtained as 0.5211, 0.8344, 0.8071, 0.9078, 0.8398 and 0.6780 respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 79. (Ref. Table 67 for respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ in the acclimation medium of 33‰ S:

The regression lines obtained under declining $pO_2$ in the acclimation salinity of 33‰ are shown in Fig. 52. The estimates of 'b' were 0.2815, 0.3876, 0.5794, 0.6653, 0.4632 and 0.4836, respectively in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. Statistically refined values of $O_2$ uptake in $pO_2$ 120 - 40 mm Hg for standard weights 10, 20 and 30 mg are given in Table 80. (Ref. Table 67 for respiratory rates in $pO_2$ 140 mm Hg.)

The 'b' values and their standard errors are given in Table 81. The regression coefficients obtained in declining oxygen tension in the three acclimation salinities were compared and the results are given in Table 82.

3.4 Oxygen consumption of C. willeyi in relation to body weight and salinity variations in declining oxygen tension:

Specimens of C. willeyi were directly transferred from the

acclimation salinities and their respiratory rates under declining $O_2$ tension were studied.

(a) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 17‰ S:

Fig. 53 shows the regression lines obtained under declining $pO_2$ when directly transferred to 17‰ S from the acclimation medium of 1‰ S. The values of 'b' obtained for $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.5867, 0.5199, 0.6389, 0.5688, 0.5738 and 0.9612, respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are presented in Table 83. (Ref. Table 75 for respiratory rates in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 33‰ S:

The regression lines for oxygen consumption against body weight obtained for animals transferred from the acclimation medium of 1‰ S to 33‰ S are shown in Fig. 54. The estimates of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.6150, 0.6030, 0.5830, 0.6436, 0.6699 and 0.3370, respectively. Statistically refined data for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 84. (Ref. Table 75 for respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 17‰ S to 1‰ S:

Fig. 55 shows the regression lines obtained under declining $O_2$

tension for animals transferred from the acclimation medium of 17‰ S to 1‰ S. The 'b' values obtained were 0.7828, 0.9221, 0.9332, 1.0175, 1.0576 and 0.9663, respectively for 140, 120, 100, 80, 60 and 40 mm Hg. The standard respiratory rates for weights 10, 20 and 30 mm Hg in $pO_2$ 120 - 40 $mm_{\lambda}^{Hg}$ are given in Table 85. (Ref. Table 75 for respiratory rates in $pO_2$ 140 mm Hg.)

(d) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 17‰ S to 33‰ S:

The regression lines obtained when the animals were transferred from the acclimation medium of 17‰ S to 33‰ S, in declining $pO_2$ are shown in Fig. 56. The values of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.4158, 0.5238, 0.4774, 0.3935, 0.2970 and 0.4123, respectively. The respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are presented in Table 86. (Ref. Table 75 for standard respiratory rates in $pO_2$ 140 mm Hg.)

(e) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 33‰ S to 17‰ S:

The regression lines of $O_2$ uptake against body weight in declining $pO_2$ obtained when the animals were transferred to 17‰ S from the acclimation medium of 33‰ S are shown in Fig. 57. The 'b' values in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.4628, 0.5315, 0.5811, 0.8063, 0.8627 and 0.6220, respectively. Respiratory rates for standard

weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 87. (Ref. Table 75 for standard respiratory rates in $pO_2$ 140 mm Hg.)

(f) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 33‰ S to 1‰ S:

Fig. 58 shows the regression lines obtained in declining $pO_2$ for animals transferred to 1‰ S from the acclimation medium of 33‰ S. Only very few animals survived below $pO_2$ 100 mm Hg in this series of experiments. The estimates of 'b' in $pO_2$ 140, 120 and 100 mm Hg were 0.7437, 0.9441 and 1.3252, respectively. The respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 and 100 mm Hg are given in Table 88. (Ref. Table 75 for respiratory rates in $pO_2$ 140 mm Hg.)

The 'b' values and their standard errors in declining oxygen tension in various salinities are shown in Table 89.

The values were compared and the results are presented in Table 90.

4. Lethal of level of oxygen concentration for S. annandalei, C. fluviatilis and C. willeyi in various salinities.

Each experiment on oxygen consumption was continued till the death of the animal and the oxygen tension in the experimental medium at the time of death was noted and is expressed as the lower lethal level of $pO_2$. The values obtained did not show any relationship with the body weight in the three species. The mean values of the lethal level of $O_2$ tension in the acclimation salinities and in other experimental salinities are given in Table 91 and Fig. 59.

Table 11. Oxygen uptake and metabolic rate of S. annandalei in the acclimation medium of 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 7.2 | 8.0 | 1111.1 |
| 11.5 | 6.4 | 556.5 |
| 13.4 | 9.4 | 701.5 |
| 15.3 | 9.4 | 614.4 |
| 15.7 | 7.4 | 471.3 |
| 18.4 | 8.7 | 472.8 |
| 18.5 | 10.0 | 540.5 |
| 20.5 | 8.6 | 419.5 |
| 22.4 | 9.5 | 424.1 |
| 22.5 | 9.6 | 426.7 |
| 22.5 | 8.8 | 391.1 |
| 23.3 | 8.3 | 356.2 |
| 25.2 | 11.0 | 436.5 |
| 26.5 | 11.7 | 441.5 |
| 27.1 | 9.8 | 361.6 |
| 27.1 | 10.0 | 369.0 |
| 27.5 | 8.6 | 312.7 |
| 28.5 | 9.0 | 315.8 |
| 28.6 | 8.5 | 297.2 |
| 28.9 | 11.8 | 408.3 |
| 30.3 | 10.8 | 356.4 |
| 30.5 | 8.9 | 291.8 |
| 31.7 | 9.5 | 299.7 |
| 32.4 | 9.4 | 290.1 |
| 35.0 | 9.5 | 271.4 |
| 36.0 | 14.0 | 388.9 |
| 37.1 | 9.3 | 250.7 |
| 38.0 | 10.7 | 281.6 |
| 38.5 | 13.8 | 358.4 |
| 46.3 | 11.2 | 241.9 |
| 48.0 | 15.6 | 325.0 |
| 49.7 | 14.7 | 295.8 |
| 55.0 | 12.9 | 234.6 |
| 57.2 | 15.7 | 274.5 |

Table 12. Oxygen uptake and metabolic rate of S. annandalei in the acclimation medium of 17‰ S in $pO_2$ 140 mm Hg

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 13.6 | 7.0 | 514.7 |
| 14.2 | 7.2 | 507.0 |
| 15.1 | 7.8 | 516.6 |
| 16.2 | 8.6 | 530.9 |
| 17.9 | 8.0 | 446.9 |
| 20.3 | 8.2 | 403.9 |
| 22.9 | 8.4 | 366.8 |
| 25.7 | 8.3 | 323.0 |
| 29.2 | 8.4 | 287.7 |
| 29.3 | 8.6 | 293.5 |
| 33.0 | 9.5 | 316.7 |
| 31.4 | 9.5 | 302.5 |
| 33.4 | 10.1 | 302.4 |
| 38.9 | 11.1 | 285.3 |
| 40.5 | 12.7 | 313.6 |
| 44.2 | 11.5 | 260.2 |
| 52.6 | 13.0 | 247.1 |
| 66.5 | 16.8 | 252.6 |

Table 13. Oxygen uptake and metabolic rate of S. annandalei in the acclimation medium of 33‰ S in $pO_2$ 140 mm Hg

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 13.9 | 7.8 | 561.2 |
| 15.1 | 8.8 | 582.8 |
| 16.1 | 9.0 | 559.0 |
| 17.0 | 7.9 | 464.7 |
| 19.7 | 8.7 | 441.6 |
| 20.1 | 8.7 | 432.8 |
| 20.2 | 9.2 | 455.4 |
| 22.6 | 9.3 | 411.5 |
| 25.0 | 11.2 | 448.0 |
| 30.6 | 12.6 | 411.8 |
| 33.0 | 11.0 | 333.3 |
| 34.5 | 11.5 | 333.3 |
| 34.8 | 11.4 | 327.6 |
| 40.2 | 12.8 | 318.4 |
| 45.3 | 13.4 | 295.8 |
| 51.5 | 14.6 | 283.5 |
| 57.9 | 14.8 | 255.6 |
| 64.0 | 17.5 | 273.4 |

Table 14. Statistical analysis of the data obtained for S. annandalei in the acclimation salinities in $pO_2$ 140 mm Hg. n = number of experiments; b = regression coefficient; r = correlation coefficient; $S_b$= Standard error of b; $t_b$ = Student's t value; p = Probability level

| Salinity ‰ | n | b | b-1 | r | $S_b$ | $t_b$ | p |
|---|---|---|---|---|---|---|---|
| 1 | 34 | 0.3423 | - 0.6577 | 0.7397 | 0.0551 | 6.2178 | <0.001 |
| 17 | 18 | 0.4457 | - 0.5543 | 0.8976 | 0.0547 | 8.1441 | <0.001 |
| 33 | 18 | 0.4854 | - 0.5146 | 0.9678 | 0.0316 | 15.3837 | <0.001 |

Table 15. $O_2$ uptake and metabolic rate of S. annandalei of standard weights 10, 20, 30, 40, 50 and 60 mg in the acclimation salinities in $pO_2$ 140 mm Hg. (Values taken from figs.7-12)

| Salinity ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|
| 1 | 10 | 7.202 | 720.2 | 381.2 |
| | 20 | 9.131 | 456.6 | |
| | 30 | 10.49 | 349.7 | |
| | 40 | 11.58 | 289.5 | |
| | 50 | 12.50 | 250.0 | |
| | 60 | 13.29 | 221.5 | |
| 17 | 10 | 6.049 | 604.9 | 347.4 |
| | 20 | 8.239 | 412.0 | |
| | 30 | 9.872 | 329.1 | |
| | 40 | 11.22 | 280.5 | |
| | 50 | 12.40 | 248.0 | |
| | 60 | 13.45 | 224.2 | |
| 33 | 10 | 6.630 | 663.0 | 397.0 |
| | 20 | 9.283 | 464.2 | |
| | 30 | 11.30 | 376.7 | |
| | 40 | 12.99 | 324.8 | |
| | 50 | 14.48 | 289.6 | |
| | 60 | 15.82 | 263.7 | |

Table 16. Comparison of regression coefficients for S. annandalei in the acclimation media in $pO_2$ 140 mm Hg.

| Comparing media ‰ S | Probability |
|---|---|
| 1 and 17 | N.S. |
| 1 and 33 | 0.02 - 0.05 |
| 17 and 33 | N.S. |

(N.S. = Not significant)

Table 17. Oxygen uptake and metabolic rate of S. annandalei when transferred from the acclimation medium of 1‰ S to 17‰ S in $pO_2$ 140 mm Hg

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 13.1 | 7.0 | 534.4 |
| 15.3 | 8.4 | 549.0 |
| 16.5 | 8.4 | 509.1 |
| 19.1 | 9.0 | 471.2 |
| 19.7 | 8.3 | 421.3 |
| 24.6 | 9.7 | 394.3 |
| 24.8 | 10.6 | 427.4 |
| 30.8 | 10.9 | 353.9 |
| 31.4 | 11.4 | 363.1 |
| 33.8 | 9.8 | 289.9 |
| 35.4 | 12.7 | 358.8 |
| 38.9 | 10.8 | 277.6 |
| 41.0 | 12.8 | 312.2 |
| 42.5 | 11.7 | 275.3 |
| 50.3 | 14.1 | 280.3 |
| 53.1 | 14.8 | 278.7 |
| 56.3 | 16.4 | 291.3 |
| 57.0 | 16.5 | 289.5 |

Table 18. Oxygen uptake and metabolic rate of S. annandalei when transferred from the acclimation medium of 1‰ S to 33‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 14.4 | 5.0 | 347.2 |
| 18.0 | 5.4 | 300.0 |
| 22.3 | 5.2 | 233.2 |
| 26.5 | 5.9 | 222.6 |
| 28.6 | 5.8 | 202.8 |
| 28.7 | 7.0 | 243.9 |
| 31.5 | 7.6 | 241.3 |
| 35.1 | 6.0 | 170.9 |
| 39.2 | 7.0 | 178.6 |
| 41.5 | 8.0 | 192.8 |
| 45.6 | 7.4 | 162.3 |
| 49.6 | 8.6 | 173.4 |
| 52.5 | 8.9 | 169.5 |
| 56.0 | 10.0 | 178.6 |
| 58.1 | 9.2 | 158.3 |
| 65.3 | 10.2 | 156.2 |

Table 19. Oxygen uptake and metabolic rate of S. annandalei when transferred from the acclimation medium of 17‰ S to 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.2 | 4.0 | 434.8 |
| 10.7 | 4.2 | 392.5 |
| 13.2 | 3.5 | 265.2 |
| 14.2 | 5.0 | 352.1 |
| 18.7 | 6.9 | 369.0 |
| 20.4 | 6.6 | 323.5 |
| 25.9 | 6.9 | 266.4 |
| 26.5 | 8.0 | 301.9 |
| 27.9 | 6.5 | 233.0 |
| 29.1 | 7.5 | 257.7 |
| 30.2 | 7.5 | 248.3 |
| 31.6 | 8.0 | 253.2 |
| 34.0 | 7.6 | 223.5 |
| 39.8 | 8.2 | 206.0 |
| 45.0 | 10.0 | 222.2 |
| 49.8 | 11.6 | 232.9 |
| 55.1 | 11.9 | 216.0 |
| 61.2 | 12.2 | 199.3 |

Table 20. Oxygen uptake and metabolic rate of S. annandalei when transferred from the acclimation medium of 33‰ S to 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate µl/g/h |
|---|---|---|
| 9.1 | 8.5 | 934.1 |
| 15.5 | 11.5 | 741.9 |
| 16.9 | 10.8 | 639.1 |
| 19.6 | 10.3 | 525.5 |
| 23.6 | 12.8 | 542.4 |
| 26.7 | 13.1 | 490.1 |
| 28.1 | 12.6 | 448.4 |
| 29.4 | 11.0 | 374.1 |
| 31.9 | 11.9 | 373.0 |
| 32.7 | 12.5 | 382.3 |
| 37.5 | 14.0 | 373.3 |
| 41.4 | 14.1 | 340.6 |
| 41.5 | 18.0 | 433.7 |
| 43.7 | 17.5 | 400.5 |
| 47.4 | 19.6 | 413.5 |
| 49.6 | 19.3 | 389.1 |
| 52.5 | 20.0 | 381.0 |
| 64.5 | 22.6 | 350.4 |

Table 21. Oxygen uptake and metabolic rate of S. annandalei of standard weights 10, 20, 30, 40, 50 and 60 mg when subjected to salinity variations in $pO_2$ 140 mm Hg. (Values taken from Figs.13, 14 and 15)

| Accl. Sal. ‰ | Exp. Sal. ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|---|
| 1 | 17 | 10 | 6.285 | 628.5 | 381.5 |
| | | 20 | 8.892 | 444.6 | |
| | | 30 | 10. 89 | 363.0 | |
| | | 40 | 12. 58 | 314.5 | |
| | | 50 | 14. 07 | 281.4 | |
| | | 60 | 15. 42 | 257.0 | |
| 1 | 33 | 10 | 3.813 | 381.3 | 230.9 |
| | | 20 | 5.384 | 269.2 | |
| | | 30 | 6.589 | 219.6 | |
| | | 40 | 7.603 | 190.1 | |
| | | 50 | 8.498 | 170.0 | |
| | | 60 | 9.305 | 155.1 | |
| 17 | 1 | 10 | 3.821 | 382.1 | 264.8 |
| | | 20 | 5.968 | 298.4 | |
| | | 30 | 7.745 | 258.2 | |
| | | 40 | 9.319 | 233.0 | |
| | | 50 | 10. 76 | 215.2 | |
| | | 60 | 12. 10 | 201.7 | |
| 33 | 17 | 10 | 8.028 | 802.8 | 484.1 |
| | | 20 | 11. 30 | 565.0 | |
| | | 30 | 13. 80 | 460.0 | |
| | | 40 | 15. 91 | 397.8 | |
| | | 50 | 17. 76 | 355.2 | |
| | | 60 | 19. 43 | 323.8 | |

## PLATE 5

Figs. 7, 9, 11. Relationships between oxygen uptake (µl/h) and body weight of S. annandalei in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs. 8, 10,12. Relationships between metabolic rate (µl/g/h) and body weight of S. annandalei in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs. 13–15. Relationships between oxygen uptake (µl/h) and body weight of S. annandalei in $pO_2$ 140 mm Hg, when subjected to salinity changes.

Table 39 for standard rates in the acclimation salinities).

Results of the statistical analysis of the data obtained under variations in salinity are shown in Table 48.

The regression coefficients of $O_2$ uptake against body weight in varying salinities were compared and the results are given in Table 49.

2.3. Oxygen consumption of C. fluviatilis in relation to body weight and declining oxygen tension in the acclimation media

Oxygen consumption in relation to body weight of C. fluviatilis in the acclimation media of 1, 17 and 33‰ S in declining partial pressure of oxygen ($pO_2$) was studied.

(a) Oxygen consumption in declining $pO_2$ in the acclimation medium of 1‰ S:

The regression lines obtained under declining $pO_2$ in the acclimation salinity of 1‰ are shown in Fig. 32. The values of 'b' obtained in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.2495, 0.1819, 0.1581, 0.1830, 0.2471 and 0.3408, respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 50. (Ref. Table 39 for the respiratory rates in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $O_2$ tension in the acclimation medium of 17‰ S:

The relationships between body weight and respiration of animals

in the acclimation medium of 17‰ S in declining oxygen tension are illustrated in Fig. 33. The values of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were obtained as 0.9173, 1.3137, 1.3370, 1.3013, 1.0980 and 0.6156, respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 51. (Ref. Table 39 for the respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ in the acclimation medium of 33‰ S:

The regression lines obtained under declining $pO_2$ in the acclimation salinity of 33‰ are shown in Fig. 34. The estimates of 'b' were 0.3663, 0.4708, 0.6172, 0.6412, 0.6361 and 0.6586, respectively in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. Statistically refined values of $O_2$ consumption in $pO_2$ 120 - 40 mm Hg for standard weights 10, 20 and 30 mg are given in Table 52. (Ref. Table 39 for the respiratory rates in $pO_2$ 140 mm Hg.)

The regression coefficients and their standard errors are given in Table 53. The values were compared for their significance in declining $pO_2$ in the acclimation salinities and the results are presented in Table 54.

2.4. Oxygen consumption of C. fluviatilis in relation to body weight and salinity variations in declining oxygen tension

Specimens of C. fluviatilis were directly transferred from the acclimation media to media of higher and lower salinities and their respiratory rates under declining $O_2$ tension were studied.

(a) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 17‰ S:

Figure 35 shows the regression lines obtained under declining $pO_2$, when directly transferred to 17‰ S from the acclimation medium of 1‰ S. The values of 'b' obtained for $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.5491, 0.5054, 0.5487, 0.7694, 0.9030 and 0.7889, respectively. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are presented in Table 55. (Ref. Table 47 for respiratory rates in $pO_2$ 140 mm Hg.)

(b) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 1‰ S to 33‰ S:

The regression lines for oxygen consumption against body weight obtained for animals transferred from the acclimation medium of 1‰ S to 33‰ S are shown in Fig. 36. The estimates of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.5113, 0.6487, 0.5848, 0.4861, 0.4837, and 0.5404, respectively. Statistically refined data for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 56. (Ref. Table 47 for the standard respiratory rates in $pO_2$ 140 mm Hg.)

(c) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 17‰ S to 1‰ S:

Figure 37 shows the regression lines obtained under declining $O_2$ tension for animals transferred from the acclimation medium of 17‰ S

to 1‰ S. The 'b' values obtained were 0.6636, 0.5928, 0.6738, 0.6148, 0.5316 and 0.7939, respectively in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. The standard respiratory rates for weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 57. (Ref. Table 47 for the respiratory rates in $pO_2$ 140 mm Hg.)

(d) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 17‰ S to 33‰ S:

The regression lines are shown in Fig. 38. The values of 'b' in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg were 0.3067, 0.3814, 0.4682, 0.5245, 0.4550 and 0.4731, respectively. The respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are presented in Table 58. (Ref. Table 47 for standard respiratory rates in $pO_2$ 140 mm Hg.)

(e) Oxygen consumption in declining $pO_2$ ~~tension~~ when transferred from the acclimation medium of 33‰ S to 17‰ S:

The regression lines of $O_2$ uptake against body weight in declining $pO_2$ obtained for animals transferred to 17‰ S from the acclimation salinity of 33‰ are shown in Fig. 39. The values of 'b' were obtained as 0.3594, 0.5006, 0.5648, 0.7303, 0.9195 and 0.9595, respectively in $pO_2$ 140, 120, 100, 80, 60 and 40 mm Hg. Respiratory rates for standard weights 10, 20 and 30 mg in $pO_2$ 120 - 40 mm Hg are given in Table 59. (Ref. Table 47 for respiratory rates in $pO_2$ 140 mm Hg.)

(f) Oxygen consumption in declining $pO_2$ when transferred from the acclimation medium of 33‰ S to 1‰ S:

Fig. 40 shows the regression lines obtained in declining $pO_2$ for animals transferred to 1‰ S from the acclimation medium of 33‰ S. The estimates of 'b' in $pO_2$ 140, 120, 100, 80, 60 and

Table 29. Oxygen uptake and metabolic rate of S. annandalei of standard weights 10, 20, 30, 40, 50 and 60 mg in declining $pO_2$ when transferred to 17‰ S from the acclimation medium of 1‰ S. (Values taken from Fig. 19)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 6.285 | 628.5 |
| | 20 | 8.892 | 444.6 |
| | 30 | 10. 89 | 363.0 |
| | 40 | 12. 58 | 314.5 |
| | 50 | 14. 07 | 281.4 |
| | 60 | 15. 42 | 257.0 |
| 100 | 10 | 2.612 | 261.2 |
| | 20 | 4.343 | 217.2 |
| | 30 | 5.848 | 194.9 |
| | 40 | 7.221 | 180.5 |
| | 50 | 8.506 | 170.1 |
| | 60 | 9.723 | 162.1 |
| 80 | 10 | 1.936 | 193.6 |
| | 20 | 3.252 | 162.6 |
| | 30 | 4.401 | 146.7 |
| | 40 | 5.458 | 136.5 |
| | 50 | 6.448 | 129.0 |
| | 60 | 7.389 | 123.2 |
| 60 | 10 | 1.195 | 119.5 |
| | 20 | 2.269 | 113.5 |
| | 30 | 3.301 | 110.0 |
| | 40 | 4.308 | 107.7 |
| | 50 | 5.297 | 105.9 |
| | 60 | 6.269 | 104.5 |
| 40 | 10 | 0.1146 | 11.46 |
| | 20 | 1.683 | 84.15 |
| | 30 | 2.471 | 82.36 |
| | 40 | 3.245 | 81.12 |
| | 50 | 4.007 | 80.14 |
| | 60 | 4.764 | 79.40 |

Table 30. Oxygen uptake and metabolic rate of S. annandalei of standard weights 10, 20, 30, 40, 50 and 60 mg in declining $pO_2$ when transferred to 33‰ S from the acclimation medium of 1‰ S. (Values taken from Fig. 20)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 3.813 | 381.3 |
| | 20 | 5.384 | 269.2 |
| | 30 | 6.589 | 219.6 |
| | 40 | 7.603 | 190.1 |
| | 50 | 8.498 | 170.0 |
| | 60 | 9.305 | 155.1 |
| 100 | 10 | 3.236 | 323.6 |
| | 20 | 4.396 | 219.8 |
| | 30 | 5.260 | 175.3 |
| | 40 | 5.974 | 149.4 |
| | 50 | 6.595 | 131.9 |
| | 60 | 7.148 | 119.1 |
| 80 | 10 | 2.742 | 274.2 |
| | 20 | 3.744 | 187.2 |
| | 30 | 4.493 | 149.8 |
| | 40 | 5.114 | 127.9 |
| | 50 | 5.654 | 113.1 |
| | 60 | 6.138 | 102.3 |
| 60 | 10 | 1.770 | 177.0 |
| | 20 | 2.701 | 135.1 |
| | 30 | 3.457 | 115.2 |
| | 40 | 4.121 | 103.0 |
| | 50 | 4.722 | 94.44 |
| | 60 | 5.277 | 87.95 |
| 40 | 10 | 1.422 | 142.2 |
| | 20 | 2.061 | 103.1 |
| | 30 | 2.561 | 85.36 |
| | 40 | 2.987 | 74.67 |
| | 50 | 3.367 | 67.34 |
| | 60 | 3.713 | 61.88 |

Table 31. Oxygen uptake and metabolic rate of *S. annandalei* of standard weights 10, 20, 30, 40, 50 and 60 mg in declining $pO_2$ when transferred to 1‰ from the acclimation medium of 17‰ S. (Values taken from Fig.21 )

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 3.821 | 382.1 |
| | 20 | 5.968 | 298.4 |
| | 30 | 7.745 | 258.2 |
| | 40 | 9.319 | 233.0 |
| | 50 | 10.76 | 215.2 |
| | 60 | 12.10 | 201.7 |
| 100 | 10 | 3.108 | 310.8 |
| | 20 | 5.119 | 256.0 |
| | 30 | 6.857 | 228.6 |
| | 40 | 8.435 | 210.9 |
| | 50 | 9.906 | 198.1 |
| | 60 | 11.30 | 188.3 |
| 80 | 10 | 2.540 | 254.0 |
| | 20 | 4.222 | 211.1 |
| | 30 | 5.683 | 189.4 |
| | 40 | 7.018 | 175.5 |
| | 50 | 8.264 | 165.3 |
| | 60 | 9.445 | 157.4 |
| 60 | 10 | 1.720 | 172.0 |
| | 20 | 3.101 | 155.1 |
| | 30 | 4.378 | 145.9 |
| | 40 | 5.593 | 139.8 |
| | 50 | 6.763 | 135.3 |
| | 60 | 7.896 | 131.6 |
| 40 | 10 | 1.201 | 120.1 |
| | 20 | 2.215 | 110.8 |
| | 30 | 3.169 | 105.6 |
| | 40 | 4.086 | 102.2 |
| | 50 | 4.975 | 99.5 |
| | 60 | 5.845 | 97.4 |

Table 32. Oxygen consumption and metabolic rate of S. annandalei of standard weights 10, 20, 30, 40, 50 and 60 mg in declining $pO_2$, when transferred to 17‰ S from the acclimation medium of 33‰ S. (Values taken from Fig.22)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 7.268 | 726.8 |
| | 20 | 10.12 | 506.0 |
| | 30 | 12.28 | 409.3 |
| | 40 | 14.10 | 352.5 |
| | 50 | 15.68 | 313.6 |
| | 60 | 17.11 | 285.2 |
| 100 | 10 | 6.674 | 667.4 |
| | 20 | 8.997 | 313.6 |
| | 30 | 10.71 | 357.0 |
| | 40 | 12.13 | 303.3 |
| | 50 | 13.36 | 267.2 |
| | 60 | 14.44 | 240.7 |
| 80 | 10 | 5.740 | 574.0 |
| | 20 | 7.560 | 378.0 |
| | 30 | 8.882 | 296.1 |
| | 40 | 9.959 | 249.0 |
| | 50 | 10.88 | 217.6 |
| | 60 | 11.70 | 195.0 |
| 60 | 10 | 4.841 | 484.1 |
| | 20 | 6.207 | 310.4 |
| | 30 | 7.180 | 239.3 |
| | 40 | 7.960 | 199.0 |
| | 50 | 8.624 | 172.5 |
| | 60 | 9.206 | 153.4 |
| 40 | 10 | 2.872 | 287.2 |
| | 20 | 3.657 | 182.9 |
| | 30 | 4.211 | 140.4 |
| | 40 | 4.656 | 116.4 |
| | 50 | 5.032 | 100.6 |
| | 60 | 5.363 | 89.4 |

## PLATE 6

Figs. 16–18. Relationships between oxygen uptake (µl/h) and body weight of *S. annandalei* in declining oxygen tension ($pO_2$) in the acclimation salinities.

Figs. 19–22. Relationships between oxygen uptake (µl/h) and body weight of *S. annandalei* in declining oxygen tension ($pO_2$) when subjected to salinity changes.

PLATE 6

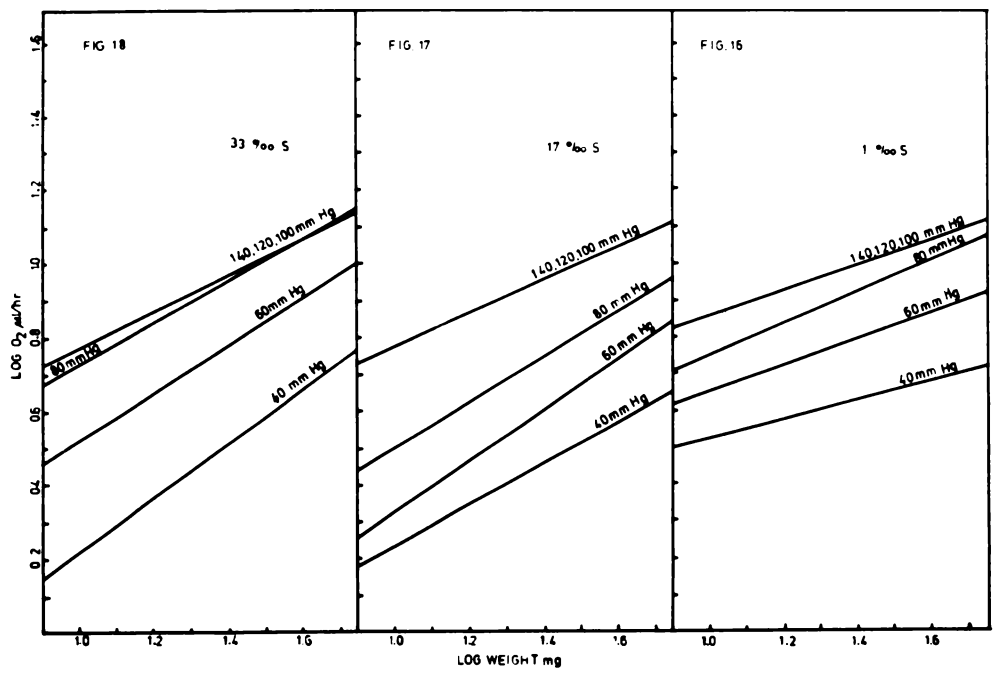


FIG. 18
33 ‰ S
140,120,100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
FIG. 17
17 ‰ S
140,120,100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
FIG. 16
1 ‰ S
140,120,100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
LOG O2 µl/hr
LOG WEIGHT mg
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

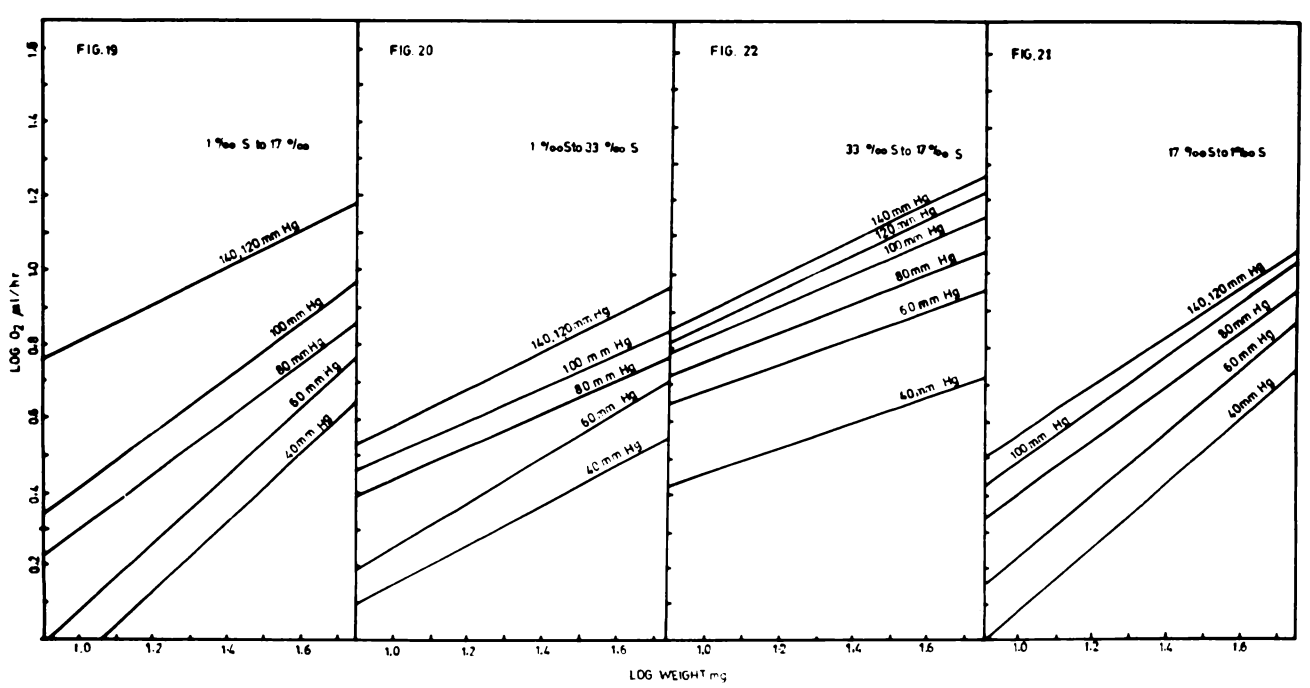


FIG. 19
1 ‰ S to 17 ‰
140,120 mm Hg
100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
FIG. 20
1 ‰ S to 33 ‰ S
140,120 mm Hg
100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
FIG. 22
33 ‰ S to 17 ‰ S
140 mm Hg
120 mm Hg
100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
FIG. 21
17 ‰ S to 1 ‰ S
140,120 mm Hg
100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
LOG O2 µl/hr
LOG WEIGHT mg
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Table 33. Regression coefficients and their standard errors in declining $pO_2$ for S. annandalei under variations in salinity. n = number of experiments; b = regression coefficient; $S_b$ = standard error of b

| Accl. Sal. ‰ | Exp. Sal. ‰ | | $pO_2$ mm Hg 140 | 120 | 100 | 80 | 60 | 40 |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.5008 | 0.5008 | 0.7334 | 0.7473 | 0.9250 | 0.9471 |
| | | $S_b$ | 0.0410 | 0.0410 | 0.0703 | 0.0787 | 0.0974 | 0.1030 |
| 1 | 33 | n | 16 | 16 | 16 | 16 | 16 | 16 |
| | | b | 0.4979 | 0.4979 | 0.4424 | 0.4498 | 0.6098 | 0.5354 |
| | | $S_b$ | 0.0528 | 0.0528 | 0.0623 | 0.0588 | 0.0736 | 0.0768 |
| 17 | 1 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.6430 | 0.6430 | 0.7204 | 0.7328 | 0.8507 | 0.8830 |
| | | $S_b$ | 0.0412 | 0.0412 | 0.0496 | 0.0508 | 0.0570 | 0.0586 |
| 33 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.4933 | 0.4778 | 0.4308 | 0.3975 | 0.3589 | 0.3485 |
| | | $S_b$ | 0.0586 | 0.0514 | 0.0481 | 0.0443 | 0.0607 | 0.0758 |

Table 34. Comparison of regression coefficients obtained for S. annandalei in declining $pO_2$ under variations in salinity

| Comparing $pO_2$ mm Hg | Probability | | | |
|---|---|---|---|---|
| | Accl. Sal. 1‰ | | Accl. Sal. 17‰ | Accl. Sal. 33‰ |
| | Exp. Sal. | | Exp. Sal. | Exp. Sal. |
| | 17‰ | 33‰ | 1‰ | 17‰ |
| 140 and 120 | N.S. | N.S. | N.S. | N.S. |
| 140 and 100 | 0.001–0.01 | N.S. | N.S. | N.S. |
| 140 and 80 | 0.001–0.01 | N.S. | N.S. | N.S. |
| 140 and 60 | < 0.001 | N.S. | 0.001–0.01 | N.S. |
| 140 and 40 | < 0.001 | N.S. | 0.001–0.01 | N.S. |
| 120 and 100 | 0.001–0.01 | N.S. | N.S. | N.S. |
| 120 and 80 | 0.001–0.01 | N.S. | N.S. | N.S. |
| 120 and 60 | < 0.001 | N.S. | 0.001–0.01 | N.S. |
| 120 and 40 | < 0.001 | N.S. | 0.001–0.01 | N.S. |
| 100 and 80 | N.S. | N.S. | N.S. | N.S. |
| 100 and 60 | N.S. | N.S. | N.S. | N.S. |
| 100 and 40 | N.S. | N.S. | 0.02–0.05 | N.S. |
| 80 and 60 | N.S. | N.S. | N.S. | N.S. |
| 80 and 40 | N.S. | N.S. | N.S. | N.S. |
| 60 and 40 | N.S. | N.S. | N.S. | N.S. |

(N.S. = Not significant)

Table 35. Oxygen uptake and metabolic rate of C. fluviatilis in the acclimation medium of 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.3 | 16.1 | 1561.2 |
| 10.9 | 16.3 | 1495.4 |
| 12.0 | 16.3 | 1358.3 |
| 12.7 | 18.6 | 1464.6 |
| 12.8 | 17.3 | 1347.7 |
| 14.7 | 17.8 | 1210.9 |
| 14.9 | 19.9 | 1335.6 |
| 15.6 | 19.9 | 1275.6 |
| 18.1 | 19.3 | 1066.3 |
| 19.8 | 19.0 | 959.6 |
| 20.0 | 21.8 | 1090.0 |
| 20.9 | 20.4 | 976.1 |
| 24.1 | 21.8 | 904.6 |
| 26.1 | 22.3 | 854.4 |
| 27.0 | 20.7 | 766.7 |
| 30.8 | 20.8 | 675.3 |
| 32.6 | 21.4 | 656.4 |
| 37.6 | 22.6 | 601.1 |

Table 36. Oxygen consumption and metabolic rate of C. fluviatilis in the acclimation medium of 17‰ S in $pO_2$ mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.3 | 3.3 | 320.4 |
| 13.2 | 4.7 | 356.1 |
| 14.2 | 3.5 | 246.5 |
| 15.9 | 4.2 | 264.2 |
| 16.9 | 6.1 | 360.9 |
| 17.4 | 4.9 | 281.6 |
| 18.6 | 3.5 | 188.2 |
| 20.7 | 6.5 | 314.0 |
| 21.0 | 6.8 | 321.4 |
| 21.3 | 6.8 | 319.2 |
| 24.3 | 6.3 | 259.3 |
| 24.4 | 8.6 | 350.4 |
| 26.0 | 6.3 | 240.4 |
| 26.4 | 7.7 | 289.8 |
| 27.1 | 8.8 | 324.7 |
| 28.1 | 9.3 | 331.0 |
| 30.6 | 7.4 | 241.8 |
| 34.5 | 9.1 | 263.8 |

Table 37. Oxygen uptake and metabolic rate of C. fluviatilis in the acclimation medium of 33‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 5.9 | 5.8 | 974.6 |
| 8.2 | 7.3 | 890.2 |
| 9.2 | 7.5 | 809.8 |
| 9.3 | 7.2 | 772.0 |
| 10.6 | 6.1 | 573.6 |
| 11.7 | 7.8 | 666.7 |
| 13.6 | 8.0 | 588.2 |
| 14.8 | 10.0 | 675.7 |
| 16.6 | 9.0 | 542.2 |
| 18.6 | 7.5 | 403.2 |
| 19.5 | 7.1 | 364.1 |
| 21.8 | 8.3 | 380.7 |
| 23.0 | 8.5 | 369.6 |
| 25.3 | 9.2 | 363.6 |
| 26.0 | 10.1 | 388.5 |
| 28.1 | 11.2 | 396.8 |
| 30.8 | 11.9 | 386.4 |
| 38.5 | 13.2 | 342.9 |

Table 38. Statistical analysis of the data obtained for C. fluviatilis in the acclimation salinities in $pO_2$ 140 mm Hg. n = number of experiments; b = regression coefficient; $S_b$ = standard error of 'b'; $t_b$ = Student's t value; P = probability level.

| Salinity ‰ | n | b | b-1 | r | $S_b$ | $t_b$ | P |
|---|---|---|---|---|---|---|---|
| 1 | 18 | 0.2495 | -0.7505 | 0.8840 | 0.0330 | 7.5632 | $<0.001$ |
| 17 | 18 | 0.9173 | -0.0827 | 0.8642 | 0.1335 | 6.8703 | $<0.001$ |
| 33 | 18 | 0.3663 | -0.6337 | 0.8380 | 0.0596 | 6.1430 | $<0.001$ |

Table 39. Oxygen uptake and metabolic rate of *C. fluviatilis* of standard weights10, 20 and 30 mg in the acclimation salinities in $pO_2$ 140 mm Hg. (Values taken from Fig.23-28)

| Salinity ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|
| 1 | 10 | 16.66 | 1666.0 | 1129.1 |
| | 20 | 19.81 | 990.5 | |
| | 30 | 21.92 | 730.7 | |
| 17 | 10 | 3.070 | 307.0 | |
| | 20 | 5.798 | 289.9 | 292.4 |
| | 30 | 8.412 | 280.4 | |
| 33 | 10 | 7.081 | 708.1 | |
| | 20 | 9.128 | 456.4 | 505.8 |
| | 30 | 10.59 | 353.0 | |

Table 40. Comparison of regression coefficients obtained for *C. fluviatilis* in the acclimation media in $pO_2$ 140 mm Hg.

| Comparing media ‰ S | Probability |
|---|---|
| 1 and 17 | $< 0.001$ |
| 1 and 33 | N.S. |
| 17 and 33 | $< 0.001$ |

(N.S. = Not significant)

Table 41. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimation medium of 1‰ S to 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.4 | 7.9 | 759.6 |
| 11.0 | 8.1 | 736.4 |
| 11.2 | 8.4 | 750.0 |
| 13.1 | 10.1 | 771.0 |
| 15.1 | 9.8 | 649.0 |
| 16.7 | 11.5 | 688.6 |
| 17.5 | 12.8 | 731.4 |
| 18.2 | 10.8 | 593.4 |
| 21.1 | 12.1 | 573.5 |
| 26.4 | 13.0 | 492.4 |
| 26.9 | 14.1 | 524.2 |
| 28.3 | 14.5 | 512.4 |
| 28.4 | 14.9 | 524.6 |
| 29.7 | 14.3 | 481.5 |
| 30.7 | 15.2 | 495.1 |
| 32.4 | 15.8 | 487.7 |
| 35.7 | 16.1 | 451.0 |
| 36.7 | 15.9 | 433.2 |

Table 42. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimationmedium of 1‰ S to 33‰ S, in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.3 | 7.8 | 757.3 |
| 10.8 | 9.2 | 851.9 |
| 11.4 | 7.9 | 693.0 |
| 15.1 | 7.4 | 490.1 |
| 16.0 | 10.0 | 625.0 |
| 16.6 | 8.6 | 518.1 |
| 20.2 | 10.1 | 500.0 |
| 20.9 | 10.7 | 512.0 |
| 21.7 | 11.3 | 520.7 |
| 23.3 | 11.8 | 506.4 |
| 24.3 | 12.0 | 493.8 |
| 24.6 | 11.3 | 459.3 |
| 30.2 | 14.7 | 486.8 |
| 32.1 | 12.0 | 373.8 |
| 32.7 | 12.3 | 376.1 |
| 33.2 | 14.1 | 424.7 |
| 36.6 | 16.3 | 445.4 |
| 37.4 | 15.2 | 406.4 |

Table 43. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimation medium of 17‰ S to 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 11.0 | 9.9 | 900.0 |
| 12.2 | 9.1 | 745.9 |
| 15.4 | 13.2 | 857.1 |
| 17.0 | 13.9 | 817.6 |
| 17.2 | 13.6 | 790.7 |
| 17.7 | 14.3 | 807.9 |
| 18.0 | 12.9 | 716.7 |
| 19.0 | 15.3 | 805.3 |
| 22.6 | 17.0 | 752.2 |
| 23.8 | 18.0 | 756.3 |
| 25.6 | 18.1 | 707.0 |
| 30.7 | 18.2 | 592.8 |
| 33.0 | 18.7 | 566.7 |
| 33.2 | 18.6 | 560.2 |
| 34.6 | 20.2 | 583.8 |
| 36.0 | 23.8 | 661.1 |
| 36.7 | 21.5 | 585.8 |
| 38.0 | 24.0 | 631.6 |

Table 44. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimation medium of 17‰ S to 33‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 7.7 | 5.6 | 727.3 |
| 9.9 | 7.9 | 798.0 |
| 14.6 | 8.3 | 568.5 |
| 15.0 | 8.1 | 540.0 |
| 15.2 | 8.1 | 532.9 |
| 16.2 | 7.8 | 481.5 |
| 16.6 | 8.3 | 500.0 |
| 18.6 | 7.2 | 387.1 |
| 18.9 | 7.0 | 370.4 |
| 22.2 | 7.9 | 355.9 |
| 26.4 | 9.0 | 340.9 |
| 28.2 | 8.9 | 315.6 |
| 28.9 | 9.1 | 314.9 |
| 29.3 | 10.2 | 348.1 |
| 32.3 | 9.7 | 300.3 |
| 32.7 | 9.9 | 302.8 |
| 33.1 | 10.3 | 311.2 |
| 40.1 | 10.8 | 269.3 |

Table 45. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimation medium of 33‰ S to 1‰ S, in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.8 | 4.0 | 370.4 |
| 11.5 | 4.6 | 400.0 |
| 12.7 | 5.3 | 417.3 |
| 16.1 | 5.9 | 366.5 |
| 16.5 | 6.5 | 393.9 |
| 17.0 | 6.1 | 358.8 |
| 17.3 | 6.2 | 358.4 |
| 18.5 | 7.2 | 389.2 |
| 22.4 | 6.0 | 267.9 |
| 23.1 | 6.3 | 272.7 |
| 23.5 | 6.9 | 293.6 |
| 25.1 | 7.4 | 294.8 |
| 26.5 | 7.7 | 290.6 |
| 27.2 | 8.7 | 319.9 |
| 27.6 | 8.5 | 308.0 |
| 33.0 | 8.8 | 266.7 |
| 38.1 | 9.1 | 238.8 |

Table 46. Oxygen uptake and metabolic rate of C. fluviatilis when transferred from the acclimation medium of 33‰ S to 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 11.3 | 7.8 | 690.3 |
| 11.6 | 7.6 | 655.2 |
| 14.2 | 9.0 | 633.8 |
| 15.2 | 9.2 | 605.3 |
| 16.5 | 9.5 | 575.8 |
| 17.6 | 10.2 | 579.5 |
| 18.2 | 10.1 | 554.9 |
| 19.1 | 9.2 | 481.7 |
| 21.4 | 9.4 | 439.3 |
| 22.8 | 11.2 | 491.2 |
| 24.5 | 10.6 | 432.7 |
| 25.0 | 10.0 | 400.0 |
| 25.4 | 10.1 | 397.6 |
| 26.0 | 10.4 | 400.0 |
| 27.8 | 10.8 | 388.5 |
| 28.6 | 12.5 | 437.1 |
| 31.0 | 11.5 | 371.0 |
| 40.5 | 12.5 | 308.6 |

Table 47. Oxygen uptake and metabolic rate of *C. fluviatilis* of standard weights 10, 20 and 30 mg when subjected to salinity variations in $pO_2$ 140 mm Hg. (Values taken from Figs. 29-31)

| Accl. Sal. ‰ | Exp. Sal. ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|---|
| 1 | 17 | 10 | 8.116 | 811.6 | 633.4 |
| | | 20 | 11.88 | 594.0 | |
| | | 30 | 14.84 | 494.7 | |
| 1 | 33 | 10 | 7.427 | 742.7 | 568.7 |
| | | 20 | 10.59 | 529.5 | |
| | | 30 | 13.02 | 434.0 | |
| 17 | 1 | 10 | 9.311 | 931.1 | 770.8 |
| | | 20 | 14.75 | 737.5 | |
| | | 30 | 19.31 | 643.7 | |
| 17 | 33 | 10 | 6.767 | 676.7 | 470.4 |
| | | 20 | 8.370 | 418.5 | |
| | | 30 | 9.477 | 315.9 | |
| 33 | 17 | 10 | 7.672 | 767.2 | 546.4 |
| | | 20 | 9.842 | 492.1 | |
| | | 30 | 11.39 | 380.0 | |
| 33 | 1 | 10 | 4.345 | 434.5 | 346.5 |
| | | 20 | 6.548 | 327.4 | |
| | | 30 | 8.324 | 277.5 | |

## PLATE 7

Figs. 23, 25, 27. Relationships between oxygen uptake (µl/h) and body weight of C. fluviatilis in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs. 24, 26, 28. Relationships between metabolic (µl/g/h) and body weight of C. fluviatilis in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs. 29-31. Relationships between oxygen uptake (µl/h) and body weight of C. fluviatilis in $pO_2$ 140 mm Hg when subjected to salinity changes.

Table 48. Statistical analysis of the data obtained on the oxygen consumption of C. fluviatilis in relation to variations in salinity in $pO_2$ 140 mm Hg. n = number of experiments; b = regression coefficient; r = correlation coefficient; $S_b$ = standard error of 'b'; $t_b$ = student's t value; p = probability level.

| Accl. Sal. ‰ | Exp. Sal. ‰ | n | b | b-1 | r | $S_b$ | $t_b$ | p |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | 18 | 0.5491 | -0.4509 | 0.9758 | 0.0313 | 17.5301 | <0.001 |
| 1 | 33 | 18 | 0.5113 | -0.4887 | 0.9132 | 0.0570 | 8.9648 | <0.001 |
| 17 | 1 | 18 | 0.6636 | -0.3364 | 0.9609 | 0.0478 | 13.8872 | <0.001 |
| 17 | 33 | 18 | 0.3067 | -0.6933 | 0.8565 | 0.0462 | 6.6384 | <0.001 |
| 33 | 17 | 18 | 0.3594 | -0.6406 | 0.9099 | 0.0410 | 8.7761 | <0.001 |
| 33 | 1 | 17 | 0.5918 | -0.4082 | 0.9313 | 0.0598 | 9.9036 | <0.001 |

Table 49. Comparison of regression coefficients obtained for C. fluviatilis when subjected to changes in salinity in $pO_2$ 140 mm Hg.

| Comparing media ‰ S | Probability |
|---|---|
| 1 and 1 to 17 | < 0.001 |
| 1 and 1 to 33 | < 0.001 |
| 1 to 17 and 1 to 33 | N.S. |
| 17 and 17 to 1 | N.S. |
| 17 and 17 to 33 | < 0.001 |
| 17 to 1 and 17 to 33 | < 0.001 |
| 33 and 33 to 17 | N.S. |
| 33 and 33 to 1 | 0.01 - 0.02 |
| 33 to 17 and 33 to 1 | 0.001 - 0.01 |
| 1 and 17 to 1 | < 0.001 |
| 1 and 33 to 1 | < 0.001 |
| 1 and 17 to 33 | N.S. |
| 17 to 1 and 33 to 1 | N.S. |
| 17 and 1 to 17 | 0.01 - 0.02 |
| 17 and 33 to 17 | < 0.001 |
| 1 to 17 and 33 to 17 | < 0.001 |
| 33 and 17 to 33 | N.S. |
| 33 and 1 to 33 | N.S. |
| 17 to 33 and 1 to 33 | 0.005 - 0.01 |
| 1 to 17 and 17 to 33 | < 0.001 |
| 33 to 17 and 17 to 1 | < 0.001 |
| 1 to 17 and 17 to 1 | N.S. |
| 1 to 33 and 33 to 1 | N.S. |

(N.S. = Not significant)

Table 50. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 1‰ S. (Values taken from Fig. 32)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 15.43 | 1543.0 |
| | 20 | 17.50 | 875.0 |
| | 30 | 18.55 | 618.3 |
| 100 | 10 | 13.77 | 1377.0 |
| | 20 | 15.37 | 768.5 |
| | 30 | 16.39 | 546.3 |
| 80 | 10 | 10.90 | 1090.0 |
| | 20 | 12.37 | 618.5 |
| | 30 | 13.32 | 444.0 |
| 60 | 10 | 8.748 | 874.8 |
| | 20 | 10.38 | 519.0 |
| | 30 | 11.48 | 382.7 |
| 40 | 10 | 4.394 | 439.4 |
| | 20 | 5.565 | 278.3 |
| | 30 | 6.390 | 213.0 |

Table 51. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 17‰ S. (Values taken from Fig. 33)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 1.753 | 175.3 |
| | 20 | 4.358 | 217.9 |
| | 30 | 7.423 | 247.4 |
| 100 | 10 | 1.420 | 142.0 |
| | 20 | 3.588 | 179.4 |
| | 30 | 6.178 | 205.9 |
| 80 | 10 | 1.118 | 111.8 |
| | 20 | 2.754 | 137.7 |
| | 30 | 4.669 | 155.6 |
| 60 | 10 | 0.1157 | 11.57 |
| | 20 | 1.849 | 92.45 |
| | 30 | 2.887 | 96.23 |
| 40 | 10 | 0.1087 | 10.87 |
| | 20 | 1.409 | 70.45 |
| | 30 | 1.809 | 60.30 |

Table 52. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 33‰ S. (Values taken from Fig. 34)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.204 | 520.4 |
| 120 | 20 | 7.211 | 360.6 |
| | 30 | 8.892 | 296.4 |
| | 10 | 3.745 | 374.5 |
| 100 | 20 | 5.745 | 287.3 |
| | 30 | 7.379 | 246.0 |
| | 10 | 2.907 | 290.7 |
| 80 | 20 | 4.534 | 226.7 |
| | 30 | 5.880 | 196.0 |
| | 10 | 2.356 | 235.6 |
| 60 | 20 | 3.664 | 183.2 |
| | 30 | 4.742 | 158.1 |
| | 10 | 1.720 | 172.0 |
| 40 | 20 | 2.714 | 135.7 |
| | 30 | 3.546 | 118.2 |

Table 53. Regression coefficients and their standard errors in declining $pO_2$ for C. fluviatilis in the acclimation salinities. $\bar{n}$ = number of experiments; b = regression coefficient; $S_b$ = standard error of b

| Salinity ‰ | | $pO_2$ mm Hg 140 | 120 | 100 | 80 | 60 | 40 |
|---|---|---|---|---|---|---|---|
| | n | 18 | 18 | 18 | 18 | 18 | 18 |
| 1 | b | 0.2495 | 0.1819 | 0.1581 | 0.1830 | 0.2471 | 0.3408 |
| | $S_b$ | 0.0330 | 0.0453 | 0.0473 | 0.0609 | 0.1014 | 0.0708 |
| | n | 18 | 18 | 18 | 18 | 18 | 18 |
| 17 | b | 0.9173 | 1.3137 | 1.3370 | 1.3013 | 1.0980 | 0.6156 |
| | $S_b$ | 0.1335 | 0.1497 | 0.1666 | 0.1705 | 0.2392 | 0.1236 |
| | n | 18 | 18 | 18 | 18 | 18 | 18 |
| 33 | b | 0.3663 | 0.4708 | 0.6172 | 0.6412 | 0.6361 | 0.6586 |
| | $S_b$ | 0.0596 | 0.0546 | 0.0873 | 0.0998 | 0.0594 | 0.0779 |

PLATE 8

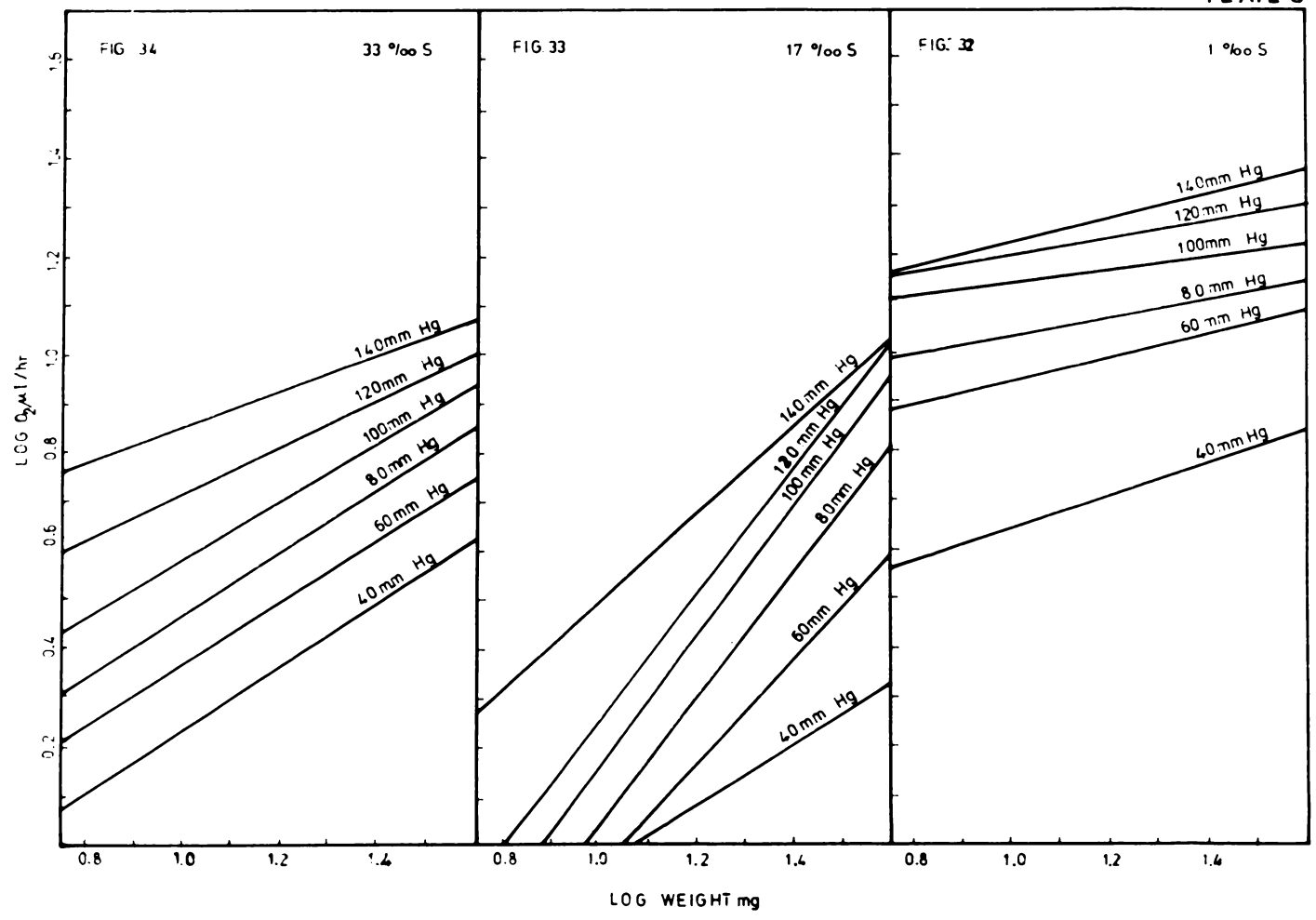


FIG 34
33 ‰ S
FIG 33
17 ‰ S
FIG 32
1 ‰ S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
LOG O2 µl/hr
LOG WEIGHT mg
0.8
1.0
1.2
1.4
0.2
0.4
0.6
0.8
1.0
1.2
1.5

Table 54. Comparison regression coefficients obtained for *C. fluviatilis* in declining $pO_2$ in the acclimation salinities.

| Comparing $pO_2$ mm Hg | Probability 1‰ S | 17‰S | 33‰ S |
|---|---|---|---|
| 140 and 120 | N.S. | N.S. | N.S. |
| 140 and 100 | N.S. | N.S. | 0.02 - 0.05 |
| 140 and 80 | N.S. | N.S. | 0.02 - 0.05 |
| 140 and 60 | N.S. | N.S. | 0.02 - 0.05 |
| 140 and 40 | N.S. | N.S. | 0.001- 0.01 |
| 120 and 100 | N.S. | N.S. | N.S. |
| 120 and 80 | N.S. | N.S. | N.S. |
| 120 and 60 | N.S. | N.S. | N.S. |
| 120 and 40 | N.S. | 0.001 - 0.01 | N.S. |
| 100 and 80 | N.S. | N.S. | N.S. |
| 100 and 60 | N.S. | N.S. | N.S. |
| 100 and 40 | 0.02-0.05 | 0.001-0.01 | N.S. |
| 80 and 60 | N.S. | N.S. | N.S. |
| 80 and 40 | N.S. | 0.001-0.01 | N.S. |
| 60 and 40 | N.S. | N.S. | N.S. |

(N.S. = Not significant)

Table 55. Oxygen uptake and metabolic rate of *C. fluviatilis* of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 17‰ S from the acclimation medium of 1‰ S. (Values taken from Fig.35)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 7.204 | 720.4 |
| | 20 | 10. 23 | 511.5 |
| | 30 | 12. 55 | 418.3 |
| 100 | 10 | 5.353 | 535.3 |
| | 20 | 7.830 | 391.5 |
| | 30 | 9.779 | 326.0 |
| 80 | 10 | 3.482 | 348.2 |
| | 20 | 5.936 | 296.8 |
| | 30 | 8.110 | 270.3 |
| 60 | 10 | 2.315 | 231.5 |
| | 20 | 4.329 | 216.5 |
| | 30 | 6.243 | 208.1 |
| 40 | 10 | 1.686 | 168.6 |
| | 20 | 2.912 | 145.6 |
| | 30 | 4.010 | 133.7 |

PLATE 7

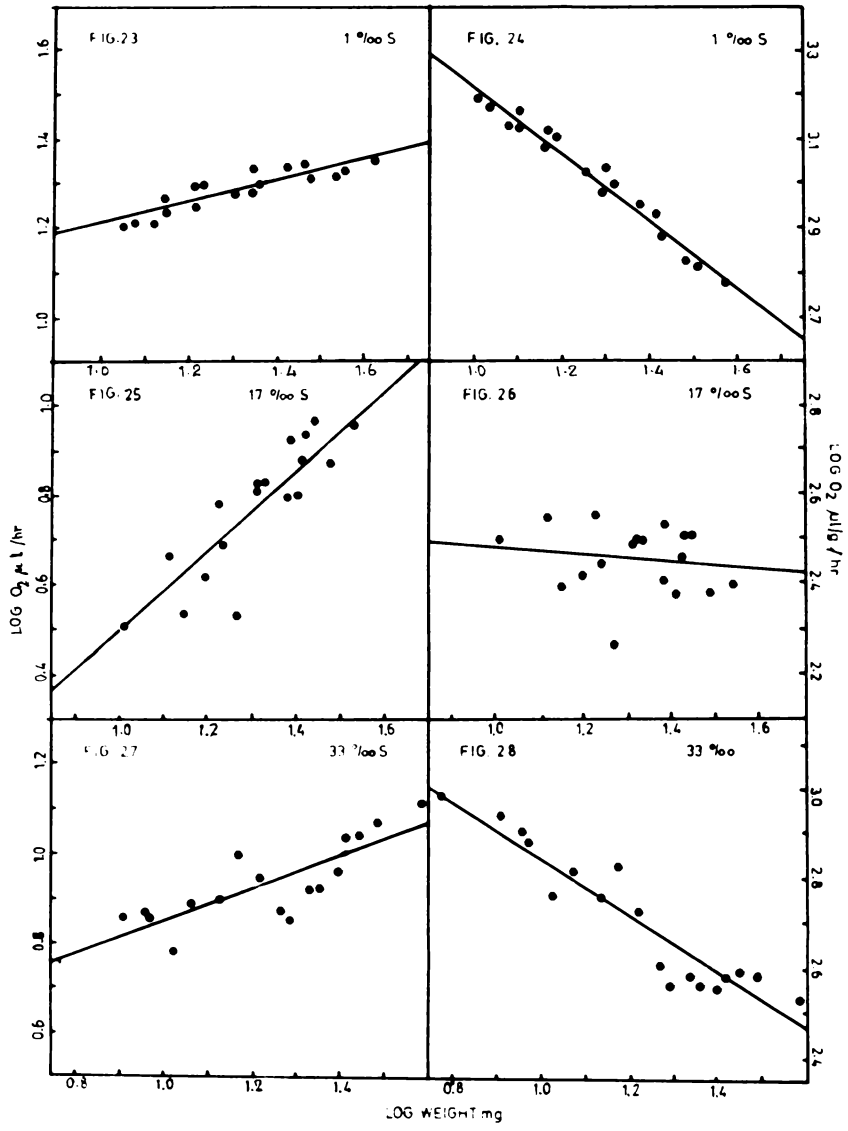


FIG. 23
1 ‰ S
FIG. 24
1 ‰ S
FIG. 25
17 ‰ S
FIG. 26
17 ‰ S
FIG. 27
33 ‰ S
FIG. 28
33 ‰
LOG O2 µl/hr
LOG WEIGHT mg
LOG O2 µl/hr

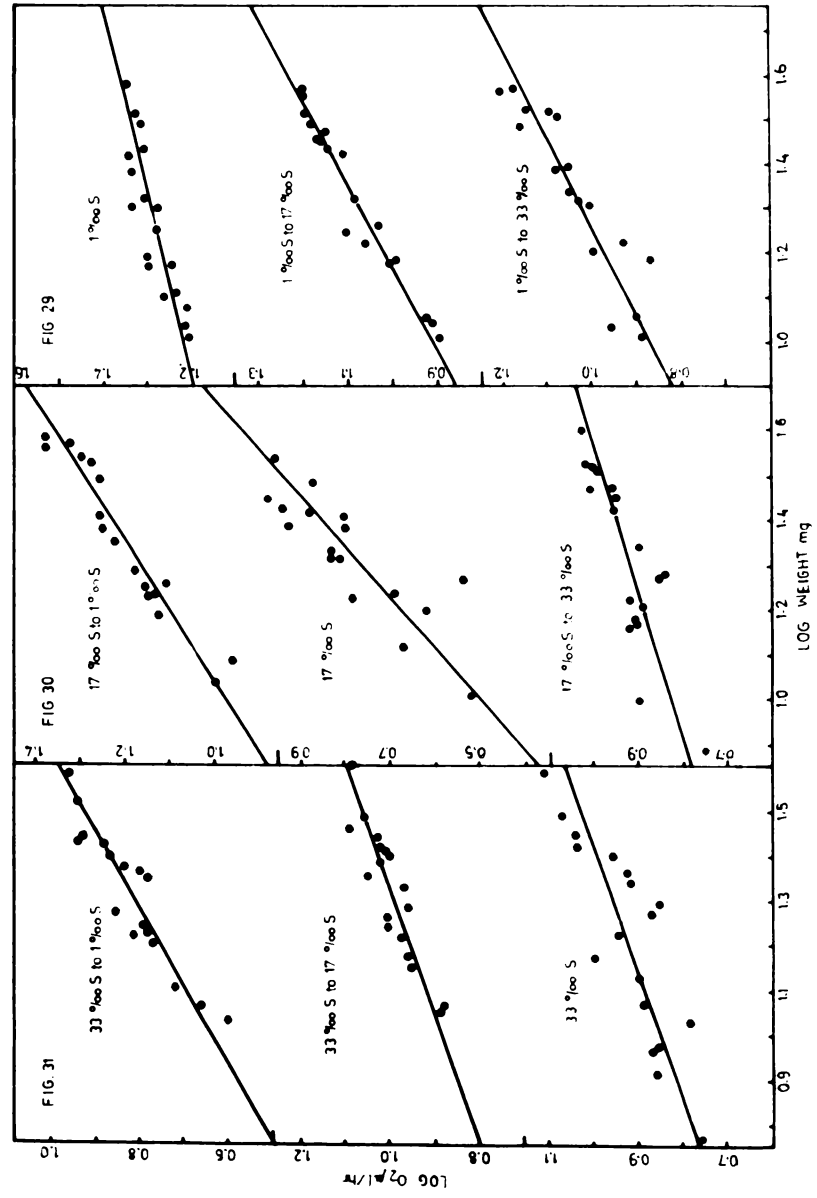


FIG 29
1 ‰ S
1 ‰ S to 17 ‰ S
1 ‰ S to 33 ‰ S
FIG 30
17 ‰ S to 1 ‰ S
17 ‰ S
17 ‰ S to 33 ‰ S
FIG 31
33 ‰ S to 1 ‰ S
33 ‰ S to 17 ‰ S
33 ‰ S
LOG O2 µl/hr
LOG WEIGHT mg

Table 56. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 33‰ S from the acclimation medium of 1‰ S.(Values taken from Fig. 36)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 5.016 | 501.6 |
| | 20 | 7.863 | 393.2 |
| | 30 | 10. 23 | 341.0 |
| 100 | 10 | 4.246 | 424.6 |
| | 20 | 6.369 | 318.5 |
| | 30 | 8.074 | 269.1 |
| 80 | 10 | 3.879 | 387.9 |
| | 20 | 5.433 | 271.7 |
| | 30 | 6.616 | 220.5 |
| 60 | 10 | 3.144 | 314.4 |
| | 20 | 4.395 | 219.8 |
| | 30 | 5.348 | 178.3 |
| 40 | 10 | 1.963 | 196.3 |
| | 20 | 2.856 | 142.8 |
| | 30 | 3.555 | 118.5 |

Table 57. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 1‰ S from the acclimation medium of 17‰ S.(Values taken from Fig. 37)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 7.582 | 758.2 |
| | 20 | 11. 44 | 572.0 |
| | 30 | 14. 54 | 484.7 |
| 100 | 10 | 5.023 | 502.3 |
| | 20 | 8.013 | 400.7 |
| | 30 | 10. 53 | 351.0 |
| 80 | 10 | 3.826 | 382.6 |
| | 20 | 5.860 | 293.0 |
| | 30 | 7.518 | 250.6 |
| 60 | 10 | 3.173 | 317.3 |
| | 20 | 4.585 | 229.3 |
| | 30 | 5.689 | 189.6 |
| 40 | 10 | 1.570 | 157.0 |
| | 20 | 2.723 | 136.2 |
| | 30 | 3.757 | 125.2 |

Table 58. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 33‰ S from the acclimation medium of 17‰ S. (Values taken from Fig. 38)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.555 | 555.5 |
| 120 | 20 | 7.236 | 361.8 |
| | 30 | 8.447 | 281.6 |
| | 10 | 4.438 | 443.8 |
| 100 | 20 | 6.139 | 307.0 |
| | 30 | 7.423 | 247.4 |
| | 10 | 3.700 | 370.0 |
| 80 | 20 | 5.322 | 266.1 |
| | 30 | 6.536 | 217.9 |
| | 10 | 2.968 | 296.8 |
| 60 | 20 | 4.069 | 203.5 |
| | 30 | 4.894 | 163.1 |
| | 10 | 1.802 | 180.2 |
| 40 | 20 | 2.501 | 125.1 |
| | 30 | 3.031 | 101.0 |

Table 59. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 17‰ S from the acclimation medium of 33‰ S.(Values taken from Fig. 39)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.217 | 521.7 |
| 120 | 20 | 7.381 | 369.1 |
| | 30 | 9.040 | 301.3 |
| | 10 | 4.061 | 406.1 |
| 100 | 20 | 6.008 | 300.4 |
| | 30 | 7.553 | 251.8 |
| | 10 | 2.915 | 291.5 |
| 80 | 20 | 4.835 | 241.8 |
| | 30 | 6.501 | 216.7 |
| | 10 | 1.844 | 184.4 |
| 60 | 20 | 3.486 | 174.3 |
| | 30 | 5.062 | 168.7 |
| | 10 | 1.171 | 117.1 |
| 40 | 20 | 2.278 | 113.9 |
| | 30 | 3.361 | 112.0 |

Table 60. Oxygen uptake and metabolic rate of C. fluviatilis of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 1‰ S from the acclimation medium of 33‰ S. (Values taken from Fig. 40)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 3.635 | 363.5 |
| 120 | 20 | 5.577 | 278.9 |
| | 30 | 7.163 | 238.8 |
| | 10 | 3.468 | 346.8 |
| 100 | 20 | 5.037 | 251.9 |
| | 30 | 6.267 | 208.9 |
| | 10 | 3.000 | 300.0 |
| 80 | 20 | 4.452 | 222.6 |
| | 30 | 5.608 | 186.9 |
| | 10 | 2.137 | 213.7 |
| 60 | 20 | 3.458 | 172.9 |
| | 30 | 4.584 | 152.8 |
| | 10 | 1.635 | 163.5 |
| 40 | 20 | 2.353 | 117.7 |
| | 30 | 2.911 | 97.0 |

## PLATE 9

Figs. 35–40. Relationships between oxygen uptake and body weight (µl/h) of *C. fluviatilis* in declining oxygen tension ($pO_2$) when subjected to salinity changes.

PLATE 9

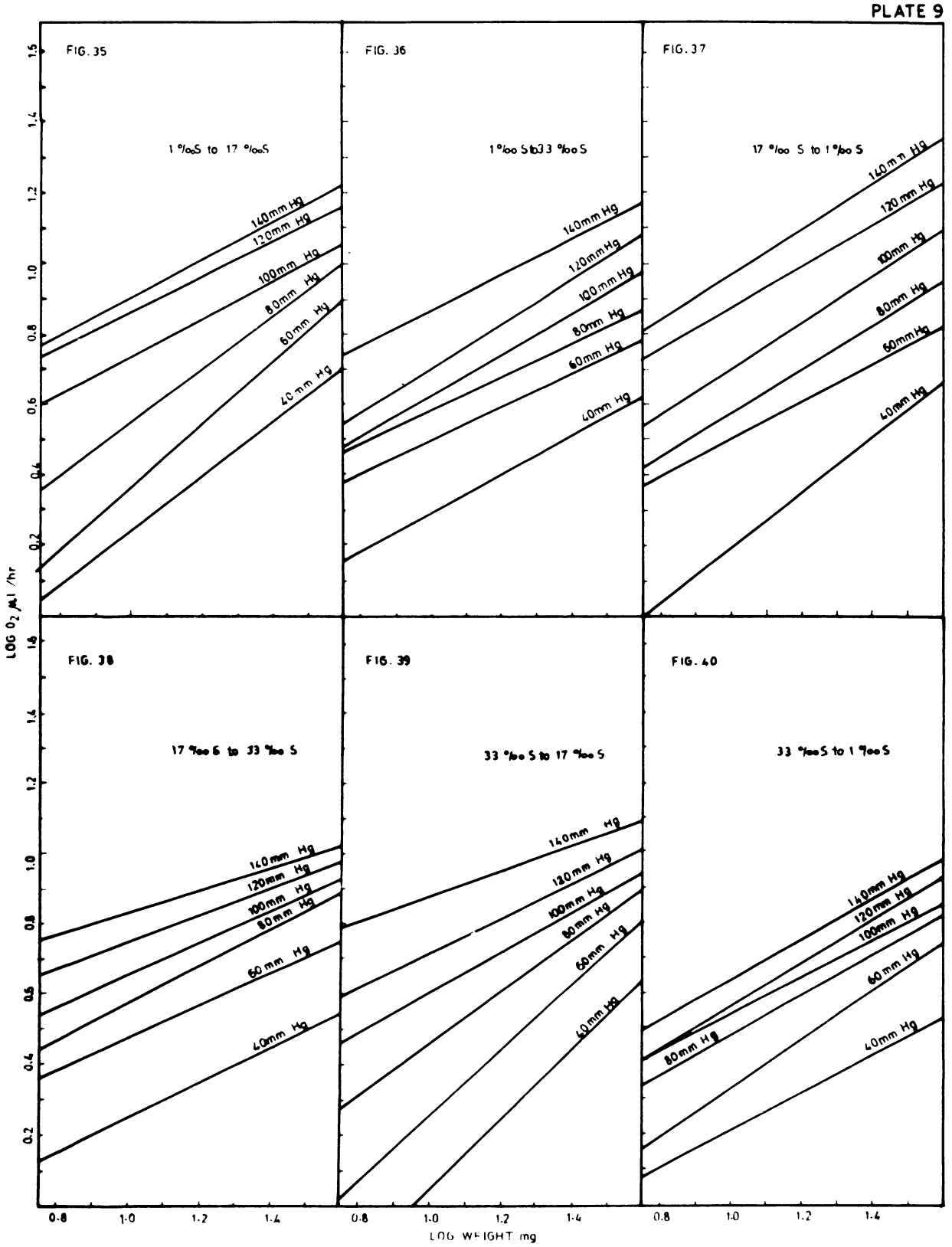


FIG. 35
1 ‰S to 17 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 36
1 ‰S to 33 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 37
17 ‰S to 1 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 38
17 ‰S to 33 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 39
33 ‰S to 17 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 40
33 ‰S to 1 ‰S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
LOG O2 µl/hr
LOG WEIGHT mg
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.5
0.8
1.0
1.2
1.4

Table 61. Regression coefficients and their standard errors in declining $pO_2$ for C. fluviatilis under variations in salinity
n = number of experiments; b = regression coefficient;
$S_b$ = standard error of b.

| Accl. Sal. ‰ | Exp. Sal. ‰ | | $pO_2$ mm Hg 140 | 120 | 100 | 80 | 60 | 40 |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.5491 | 0.5054 | 0.5487 | 0.7694 | 0.9030 | 0.7889 |
| | | $S_b$ | 0.0313 | 0.0392 | 0.0789 | 0.1239 | 0.0987 | 0.1020 |
| 1 | 33 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.5113 | 0.6487 | 0.5848 | 0.4861 | 0.4837 | 0.5404 |
| | | $S_b$ | 0.0570 | 0.0777 | 0.0671 | 0.0655 | 0.0659 | 0.0802 |
| 17 | 1 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.6636 | 0.5928 | 0.6738 | 0.6148 | 0.5316 | 0.7939 |
| | | $S_b$ | 0.0478 | 0.0657 | 0.0900 | 0.0725 | 0.0689 | 0.0739 |
| 17 | 33 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.3067 | 0.3814 | 0.4682 | 0.5245 | 0.4550 | 0.4731 |
| | | $S_b$ | 0.0462 | 0.0608 | 0.0669 | 0.0777 | 0.0637 | 0.0711 |
| 33 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.3594 | 0.5006 | 0.5648 | 0.7303 | 0.9195 | 0.9595 |
| | | $S_b$ | 0.0410 | 0.0664 | 0.0847 | 0.1093 | 0.1558 | 0.1765 |
| 33 | 1 | n | 17 | 17 | 17 | 17 | 17 | 17 |
| | | b | 0.5918 | 0.6176 | 0.5386 | 0.5694 | 0.6954 | 0.5249 |
| | | $S_b$ | 0.0598 | 0.0686 | 0.0656 | 0.0764 | 0.1174 | 0.1055 |

Table 62. Comparison of regression coefficients obtained for *C. fluviatilis* in declining $pO_2$ under variations in salinity.

| Comparing $pO_2$ mm Hg | Probability | | | | | |
|---|---|---|---|---|---|---|
| | Accl. Sal. 1‰ | | Accl. Sal. 17‰ | | Accl. Sal. 33‰ | |
| | Exp. 17‰ | Sal. 33‰ | Exp. 1‰ | Sal. 33‰ | Exp. 1‰ | Sal. 17‰ |
| 140 and 120 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 140 and 100 | N.S. | N.S. | N.S. | N.S. | N.S. | 0.02–0.05 |
| 140 and 80 | N.S. | N.S. | N.S. | 0.02–0.05 | N.S. | 0.001–0.01 |
| 140 and 60 | 0.001–0.01 | N.S. | N.S. | N.S. | N.S. | 0.001–0.01 |
| 140 and 40 | N.S. | N.S. | N.S. | N.S. | N.S. | 0.001–0.01 |
| 120 and 100 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 120 and 80 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 120 and 60 | < 0.001 | N.S. | N.S. | N.S. | N.S. | 0.02–0.05 |
| 120 and 40 | 0.01–0.02 | N.S. | N.S. | N.S. | N.S. | 0.02–0.05 |
| 100 and 80 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 100 and 60 | 0.001–0.01 | N.S. | N.S. | N.S. | N.S. | N.S. |
| 100 and 40 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 80 and 60 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 80 and 40 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 60 and 40 | N.S | N.S. | 0.01–0.02 | N.S. | N.S. | N.S. |

(N.S. = Not significant)

Table 63. Oxygen uptake and metabolic rate of C. willeyi in the acclimation medium of 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.6 | 9.5 | 984.4 |
| 11.1 | 7.9 | 711.7 |
| 11.3 | 8.8 | 778.8 |
| 12.3 | 10.1 | 821.1 |
| 12.8 | 11.3 | 882.8 |
| 12.9 | 12.0 | 926.4 |
| 15.4 | 12.5 | 811.7 |
| 15.9 | 10.6 | 666.7 |
| 19.3 | 12.2 | 632.1 |
| 22.1 | 14.4 | 651.6 |
| 22.8 | 13.0 | 570.2 |
| 23.2 | 15.9 | 685.3 |
| 23.5 | 15.4 | 655.3 |
| 24.8 | 14.8 | 596.8 |
| 25.0 | 16.1 | 644.0 |
| 25.7 | 15.7 | 610.9 |
| 25.9 | 16.6 | 640.9 |
| 29.1 | 16.2 | 556.7 |



Table 64. Oxygen uptake and metabolic rate of C. willeyi in the acclimation medium of 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 10.3 | 9.2 | 893.2 |
| 11.3 | 9.4 | 831.9 |
| 12.2 | 8.4 | 688.5 |
| 12.5 | 10.0 | 800.0 |
| 13.1 | 11.0 | 839.7 |
| 14.5 | 8.7 | 600.0 |
| 15.2 | 10.5 | 690.8 |
| 15.4 | 10.7 | 694.8 |
| 16.1 | 9.5 | 590.1 |
| 17.1 | 11.6 | 678.4 |
| 18.5 | 9.8 | 529.7 |
| 20.4 | 13.4 | 656.9 |
| 21.0 | 12.6 | 600.0 |
| 22.5 | 13.3 | 591.1 |
| 24.4 | 14.2 | 582.0 |
| 25.4 | 13.3 | 523.6 |
| 26.9 | 14.5 | 539.0 |

Table 65. Oxygen uptake and metabolic rate of C. willeyi in the acclimation medium of 33‰ in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 11.2 | 13.4 | 1196.4 |
| 12.0 | 14.8 | 1233.3 |
| 12.8 | 14.6 | 1140.6 |
| 13.5 | 14.1 | 1044.4 |
| 13.9 | 14.4 | 1036.0 |
| 14.1 | 14.9 | 1056.7 |
| 15.5 | 15.9 | 1025.8 |
| 15.8 | 15.4 | 974.7 |
| 16.6 | 15.9 | 957.8 |
| 16.9 | 14.8 | 875.7 |
| 17.8 | 15.0 | 842.7 |
| 19.1 | 16.1 | 842.9 |
| 19.9 | 15.5 | 778.9 |
| 22.3 | 16.0 | 717.5 |
| 25.6 | 16.8 | 656.3 |
| 27.5 | 18.0 | 654.5 |
| 30.1 | 18.2 | 604.7 |
| 30.6 | 19.5 | 637.3 |

Table 66. Statistical analysis of the data obtained for C. willeyi in the acclimation salinities in $pO_2$ 140 mm Hg. n = number of experiments; b = regression coefficient; $S_b$ = standard error of b, $t_b$ = student's t value; p = probability level.

| Salinity ‰ | n | b | b-1 | r | $S_b$ | $t_b$ | p |
|---|---|---|---|---|---|---|---|
| 1 | 18 | 0.5976 | -0.4024 | 0.9277 | 0.0601 | 9.9427 | $< 0.001$ |
| 17 | 17 | 0.5211 | -0.4789 | 0.8678 | 0.0770 | 6.7641 | $< 0.001$ |
| 33 | 18 | 0.2815 | -0.7185 | 0.9240 | 0.0291 | 9.6689 | $< 0.001$ |

Table 67. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in the acclimation salinities in $pO_2$ 140 mm Hg. (Values taken from Figs.41-46)

| Salinity ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|
| 1 | 10 | 8.898 | 889.8 | 711.6 |
| | 20 | 13.46 | 673.0 | |
| | 30 | 17.16 | 572.0 | |
| 17 | 10 | 8.416 | 841.6 | 647.6 |
| | 20 | 12.08 | 604.0 | |
| | 30 | 14.92 | 497.3 | |
| 33 | 10 | 13.33 | 1333.0 | 913.1 |
| | 20 | 16.21 | 810.5 | |
| | 30 | 18.17 | 605.7 | |

Table 68. Comparison of regression coefficients obtained for C. willeyi in the acclimation media in $pO_2$ 140 mm Hg.

| Comparing media ‰ | Probability |
|---|---|
| 1 and 17 | N.S. |
| 1 and 33 | $< 0.001$ |
| 17 and 33 | 0.001-0.01 |

(N.S. = Not significant)

Table 69. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 1‰ S to 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 11.1 | 8.2 | 738.7 |
| 12.3 | 8.3 | 674.8 |
| 13.6 | 7.1 | 522.1 |
| 14.0 | 8.4 | 600.0 |
| 14.3 | 6.9 | 482.5 |
| 17.0 | 9.2 | 541.2 |
| 18.3 | 8.2 | 448.1 |
| 19.2 | 7.9 | 411.5 |
| 22.3 | 10.2 | 457.4 |
| 24.6 | 10.8 | 439.0 |
| 24.8 | 11.0 | 443.5 |
| 25.0 | 10.7 | 428.0 |
| 26.1 | 11.3 | 433.0 |
| 27.5 | 12.0 | 436.4 |
| 27.8 | 12.6 | 453.2 |
| 30.5 | 13.5 | 442.6 |
| 31.0 | 13.0 | 419.4 |
| 32.2 | 13.7 | 425.5 |

Table 70. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 1‰ S to 33‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 11.1 | 6.8 | 612.6 |
| 11.6 | 7.4 | 637.9 |
| 12.3 | 8.0 | 650.4 |
| 12.6 | 9.0 | 714.3 |
| 15.8 | 8.8 | 557.0 |
| 15.9 | 8.7 | 547.2 |
| 16.7 | 10.7 | 640.7 |
| 16.9 | 8.6 | 508.9 |
| 17.2 | 9.9 | 575.6 |
| 18.9 | 11.5 | 608.5 |
| 20.4 | 10.0 | 490.2 |
| 20.9 | 10.2 | 488.0 |
| 25.1 | 12.4 | 494.0 |
| 25.4 | 12.0 | 472.4 |
| 28.8 | 13.2 | 458.3 |
| 29.1 | 13.6 | 467.4 |
| 30.9 | 13.8 | 446.6 |

Table 71. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 17‰ S to 1‰ S in 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.6 | 5.0 | 520.8 |
| 10.3 | 5.5 | 534.0 |
| 10.8 | 7.0 | 648.1 |
| 12.9 | 8.3 | 643.4 |
| 14.2 | 8.0 | 563.4 |
| 14.3 | 8.8 | 615.4 |
| 16.5 | 10.3 | 624.2 |
| 16.8 | 10.7 | 636.9 |
| 17.9 | 9.6 | 536.3 |
| 18.8 | 9.3 | 494.7 |
| 21.7 | 10.0 | 460.8 |
| 22.6 | 11.7 | 517.7 |
| 27.5 | 13.0 | 472.7 |
| 28.2 | 13.5 | 478.7 |
| 29.0 | 13.6 | 469.0 |

Table 72. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 17‰ S to 33‰ S in 140 mm Hg

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.1 | 7.4 | 813.8 |
| 9.3 | 7.8 | 838.7 |
| 10.6 | 8.1 | 764.2 |
| 11.3 | 7.5 | 663.7 |
| 11.5 | 8.1 | 704.3 |
| 11.7 | 8.5 | 726.5 |
| 12.3 | 9.2 | 748.0 |
| 12.7 | 9.7 | 763.8 |
| 15.1 | 9.8 | 649.0 |
| 18.1 | 9.2 | 508.3 |
| 18.5 | 10.1 | 545.9 |
| 21.7 | 9.6 | 442.4 |
| 22.5 | 11.3 | 502.2 |
| 26.3 | 10.8 | 410.6 |
| 26.7 | 12.7 | 475.7 |
| 28.9 | 12.6 | 436.0 |
| 30.2 | 12.8 | 423.8 |
| 31.1 | 13.0 | 418.0 |

Table 73. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 33‰ S to 1‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.6 | 5.2 | 541.7 |
| 9.9 | 6.6 | 666.7 |
| 12.3 | 6.8 | 552.8 |
| 12.7 | 7.1 | 559.1 |
| 12.9 | 8.1 | 627.9 |
| 13.2 | 8.0 | 606.1 |
| 13.5 | 8.4 | 622.2 |
| 14.0 | 8.5 | 607.1 |
| 14.3 | 8.9 | 622.4 |
| 15.5 | 9.0 | 580.6 |
| 16.6 | 8.8 | 530.1 |
| 16.7 | 9.0 | 538.9 |
| 23.1 | 10.8 | 467.5 |
| 27.9 | 13.4 | 480.3 |

Table 74. Oxygen uptake and metabolic rate of C. willeyi when transferred from the acclimation medium of 33‰ S to 17‰ S in $pO_2$ 140 mm Hg.

| Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|
| 9.3 | 8.7 | 935.5 |
| 10.3 | 9.5 | 922.3 |
| 11.4 | 8.9 | 780.7 |
| 11.5 | 9.5 | 826.1 |
| 12.3 | 8.0 | 650.4 |
| 12.7 | 10.0 | 787.4 |
| 13.5 | 10.5 | 777.8 |
| 13.7 | 11.0 | 802.9 |
| 14.1 | 10.7 | 758.9 |
| 14.7 | 11.8 | 802.7 |
| 15.2 | 11.4 | 750.0 |
| 15.8 | 10.8 | 683.5 |
| 16.4 | 11.3 | 689.0 |
| 20.0 | 12.4 | 620.0 |
| 22.7 | 11.9 | 524.2 |
| 24.0 | 12.7 | 529.2 |
| 26.5 | 14.3 | 539.6 |
| 27.0 | 14.7 | 544.4 |

Table 75. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg when subjected to salinity variations in $pO_2$ 140 mm Hg. (Values taken from Figs.47-49)

| Accl. Sal. ‰ | Exp. Sal. ‰ | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h | Average metabolic rate $O_2$ µl/g/h |
|---|---|---|---|---|---|
| 1 | 17 | 10 | 6.492 | 649.2 | 516.3 |
| | | 20 | 9.750 | 487.5 | |
| | | 30 | 12. 37 | 412.3 | |
| 1 | 33 | 10 | 6.904 | 690.4 | 557.1 |
| | | 20 | 10. 57 | 528.5 | |
| | | 30 | 13. 57 | 452.3 | |
| 17 | 1 | 10 | 6.099 | 609.9 | 538.5 |
| | | 20 | 10. 50 | 525.0 | |
| | | 30 | 14. 42 | 480.7 | |
| 17 | 33 | 10 | 7.865 | 786.5 | 575.0 |
| | | 20 | 10. 49 | 524.5 | |
| | | 30 | 12. 42 | 414.0 | |
| 33 | 17 | 10 | 8.904 | 890.4 | 665.7 |
| | | 20 | 12. 27 | 613.5 | |
| | | 30 | 14. 80 | 493.3 | |
| 33 | 1 | 10 | 6.248 | 624.8 | 540.0 |
| | | 20 | 10. 47 | 523.5 | |
| | | 30 | 14. 15 | 471.7 | |

Table 76. Statistical analysis of the data obtained on the oxygen consumption of C. willeyi in relation to variations in salinity in $pO_2$ 140 mm Hg. n = number of experiments; b = regression coefficient; & r = correlation coefficient; $S_b$ = standard error of b; $t_b$ = student's t value; P = Proability level.

| Accl. Sal. ‰ | Exp. Sal. ‰ | n | b | b-1 | r | $S_b$ | $t_b$ | P |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | 18 | 0.5867 | -0.4133 | 0.9094 | 0.0671 | 8.7460 | <0.001 |
| 1 | 33 | 17 | 0.6150 | -0.3850 | 0.9463 | 0.0542 | 11.3391 | <0.001 |
| 17 | 1 | 15 | 0.7828 | -0.2172 | 0.9472 | 0.0735 | 10.6471 | <0.001 |
| 17 | 33 | 18 | 0.4158 | -0.5842 | 0.9415 | 0.0372 | 11.1795 | <0.001 |
| 33 | 17 | 18 | 0.4628 | -0.5372 | 0.9078 | 0.0535 | 8.6576 | <0.001 |
| 33 | 1 | 14 | 0.7437 | -0.2563 | 0.9467 | 0.0731 | 10.1799 | <0.001 |

## PLATE 10

Figs. 41, 43, 45. Relationships between oxygen uptake (µl/h) and body weight of C. willeyi in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs. 42, 44, 46. Relationships between metabolic rate (µl/g/h) and body weight of C. willeyi in the acclimation salinities, in $pO_2$ 140 mm Hg.

Figs.47–49. Relationships between oxygen uptake (µl/h) and body weight of C. willeyi in $pO_2$ 140 mm Hg, when subjected to salinity changes.

PLATE 10

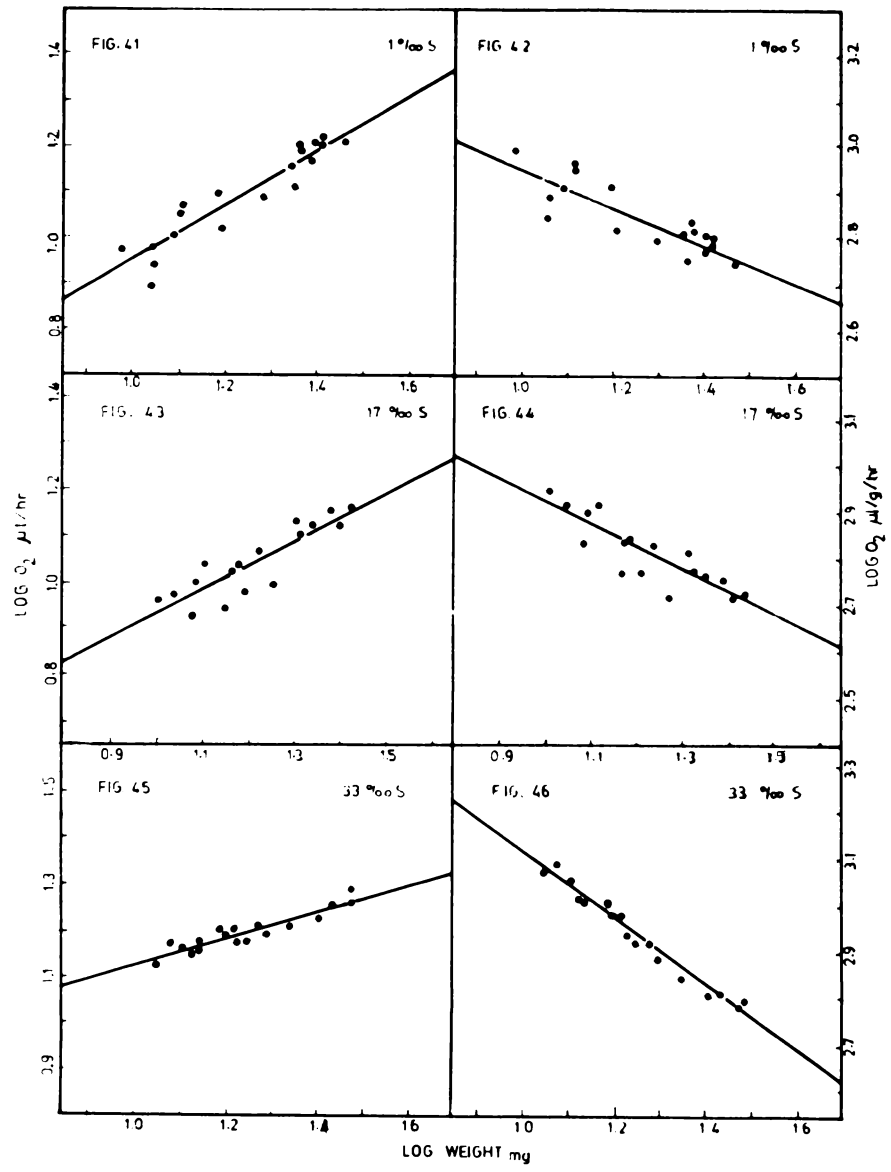


FIG. 41
1 ‰ S
FIG. 42
1 ‰ S
FIG. 43
17 ‰ S
FIG. 44
17 ‰ S
FIG. 45
33 ‰ S
FIG. 46
33 ‰ S
LOG O2 µl/hr
LOG O2 µl/g/hr
LOG WEIGHT mg

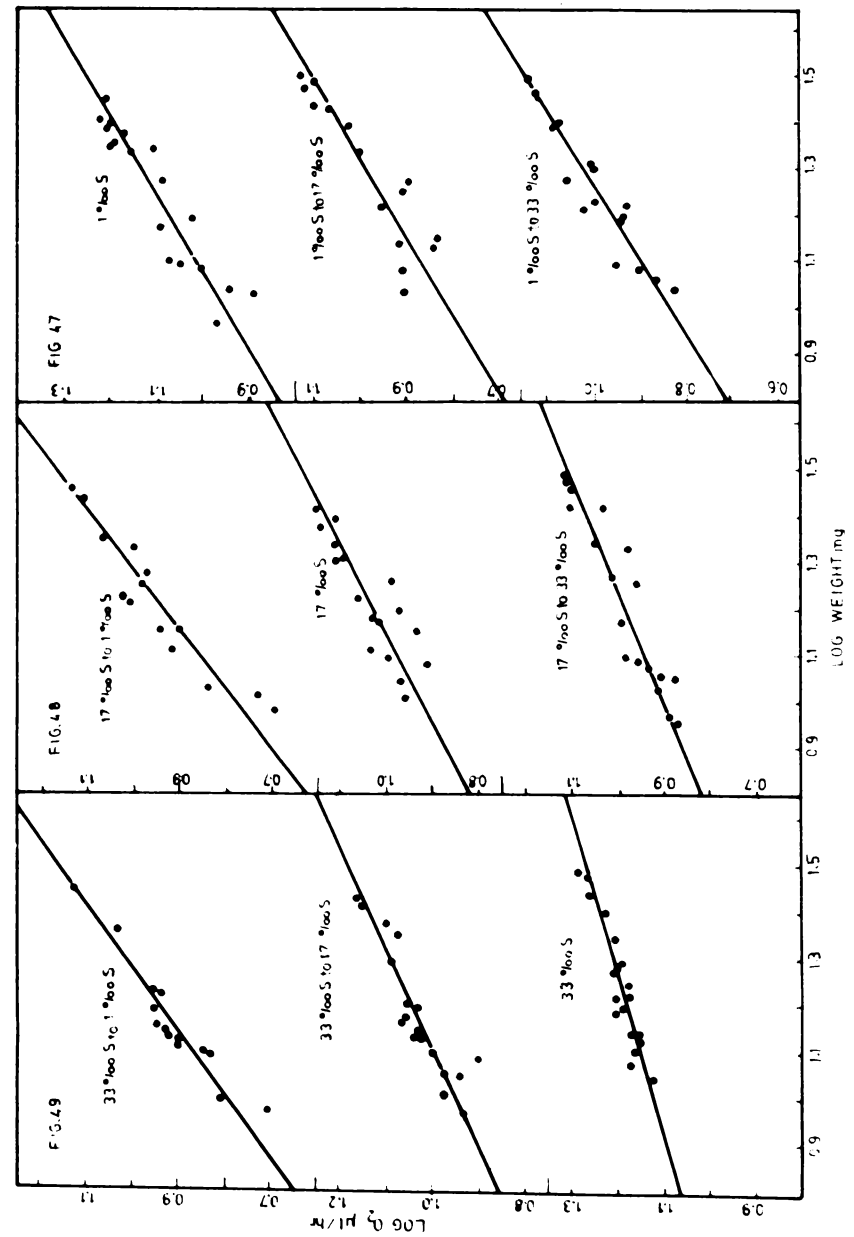


FIG 47
1 ‰ S
1 ‰ S to 17 ‰ S
1 ‰ S to 33 ‰ S
FIG.48
17 ‰ S to 1 ‰ S
17 ‰ S
17 ‰ S to 33 ‰ S
FIG.49
33 ‰ S to 1 ‰ S
33 ‰ S to 17 ‰ S
33 ‰ S
LOG O2 µl/hr
LOG WEIGHT mg

Table 77. Comparison of regression coefficients obtained for C. willeyi when subjected to changes in salinity, in $pO_2$ 140 mm Hg.

| Comparing media ‰ S | Probability |
|---|---|
| 1 and 1 to 17 | N.S. |
| 1 and 1 to 33 | N.S. |
| 1 to 17 and 1 to 33 | N.S. |
| 17 and 17 to 1 | 0.02–0.05 |
| 17 and 17 to 33 | N.S. |
| 17 to 1 and 17 to 33 | < 0.001 |
| 33 and 33 to 17 | 0.001–0.01 |
| 33 and 33 to 1 | < 0.001 |
| 33 to 17 and 33 to 1 | 0.001–0.01 |
| 1 and 17 to 1 | N.S. |
| 1 and 33 to 1 | N.S. |
| 17 to 1 and 33 to 1 | N.S. |
| 17 and 1 to 17 | N.S. |
| 17 and 33 to 17 | N.S. |
| 1 to 17 and 33 to 17 | N.S. |
| 33 and 17 to 33 | 0.001–0.01 |
| 33 and 1 to 33 | < 0.001 |
| 17 to 33 and 1 to 33 | 0.001–0.01 |
| 1 to 17 and 17 to 33 | 0.02–0.05 |
| 33 to 17 and 17 to 1 | 0.001–0.01 |
| 1 to 17 and 17 to 1 | N.S. |
| 1 to 33 and 33 to 1 | N.S. |

(N.S. = Not significant)

Table 78. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 1‰ S. (Values taken from Fig.50)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 7.647 | 764.7 |
| 120 | 20 | 11. 82 | 591.0 |
| | 30 | 15. 25 | 508.3 |
| | 10 | 6.479 | 647.9 |
| 100 | 20 | 9.462 | 473.1 |
| | 30 | 11. 81 | 393.7 |
| | 10 | 5.229 | 522.9 |
| 80 | 20 | 7.276 | 363.8 |
| | 30 | 8.826 | 294.2 |
| | 10 | 3.747 | 374.7 |
| 60 | 20 | 5.543 | 277.2 |
| | 30 | 6.828 | 227.6 |
| | 10 | 2.697 | 269.7 |
| 40 | 20 | 3.775 | 188.8 |
| | 30 | 4.596 | 153.2 |

Table 79. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 17‰ S.(Values taken from Fig.51)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.663 | 566.3 |
| 120 | 20 | 10. 10 | 505.0 |
| | 30 | 14. 17 | 472.3 |
| | 10 | 5.084 | 508.4 |
| 100 | 20 | 8.896 | 444.8 |
| | 30 | 12. 34 | 411.3 |
| | 10 | 4.002 | 400.2 |
| 80 | 20 | 7.509 | 375.5 |
| | 30 | 10. 85 | 361.7 |
| | 10 | 3.303 | 330.3 |
| 60 | 20 | 5.912 | 295.6 |
| | 30 | 8.310 | 277.0 |
| | 10 | 2.349 | 234.9 |
| 40 | 20 | 3.758 | 187.9 |
| | 30 | 4.948 | 164.9 |

Table 80. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ in the acclimation medium of 33‰ S. (Values taken from Fig. 52)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 9.831 | 983.1 |
| 120 | 20 | 12. 86 | 643.0 |
| | 30 | 15.05 | 501.7 |
| | 10 | 6.323 | .632.3 |
| 100 | 20 | 9.450 | 472.5 |
| | 30 | 11. 95 | 398.3 |
| | 10 | 4.251 | 425.1 |
| 80 | 20 | 6.742 | 337.1 |
| | 30 | 8.831 | 294.4 |
| | 10 | 3.589 | 358.9 |
| 60 | 20 | 4.948 | 247.4 |
| | 30 | 5.970 | 199.0 |
| | 10 | 2.299 | 229.9 |
| 40 | 20 | 3.215 | 160.8 |
| | 30 | 3.911 | 130.4 |

Table 81. Regression coefficients and their standard errors in declining $pO_2$ for C. willeyi in the acclimation salinities. n = number of experiments; b = regression coefficients; $S_b$ = standard error of b.

| Salinity ‰ | | $pO_2$ mm Hg 140 | 120 | 100 | 80 | 60 | 40 |
|---|---|---|---|---|---|---|---|
| | n | 18 | 18 | 18 | 18 | 18 | 18 |
| 1 | b | 0.5976 | 0.6283 | 0.5466 | 0.4767 | 0.5648 | 0.4853 |
| | $S_b$ | 0.0601 | 0.0504 | 0.0654 | 0.0458 | 0.0754 | 0.0890 |
| | n | 17 | 17 | 17 | 17 | 17 | 17 |
| 17 | b | 0.5211 | 0.8344 | 0.8071 | 0.9078 | 0.8398 | 0.6780 |
| | $S_b$ | 0.0770 | 0.0898 | 0.0877 | 0.0978 | 0.0794 | 0.0705 |
| 33 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | b | 0.2815 | 0.3876 | 0.5794 | 0.6653 | 0.4632 | 0.4836 |
| | $S_b$ | 0.0291 | 0.0364 | 0.0503 | 0.0812 | 0.0768 | 0.0741 |

## PLATE 11

Figs. 50 – 52. Relationships between oxygen uptake (µl/h) and body weight of *C. willeyi* in declining oxygen tension ($\overline{pO_2}$) in the acclimation salinities.

PLATE II

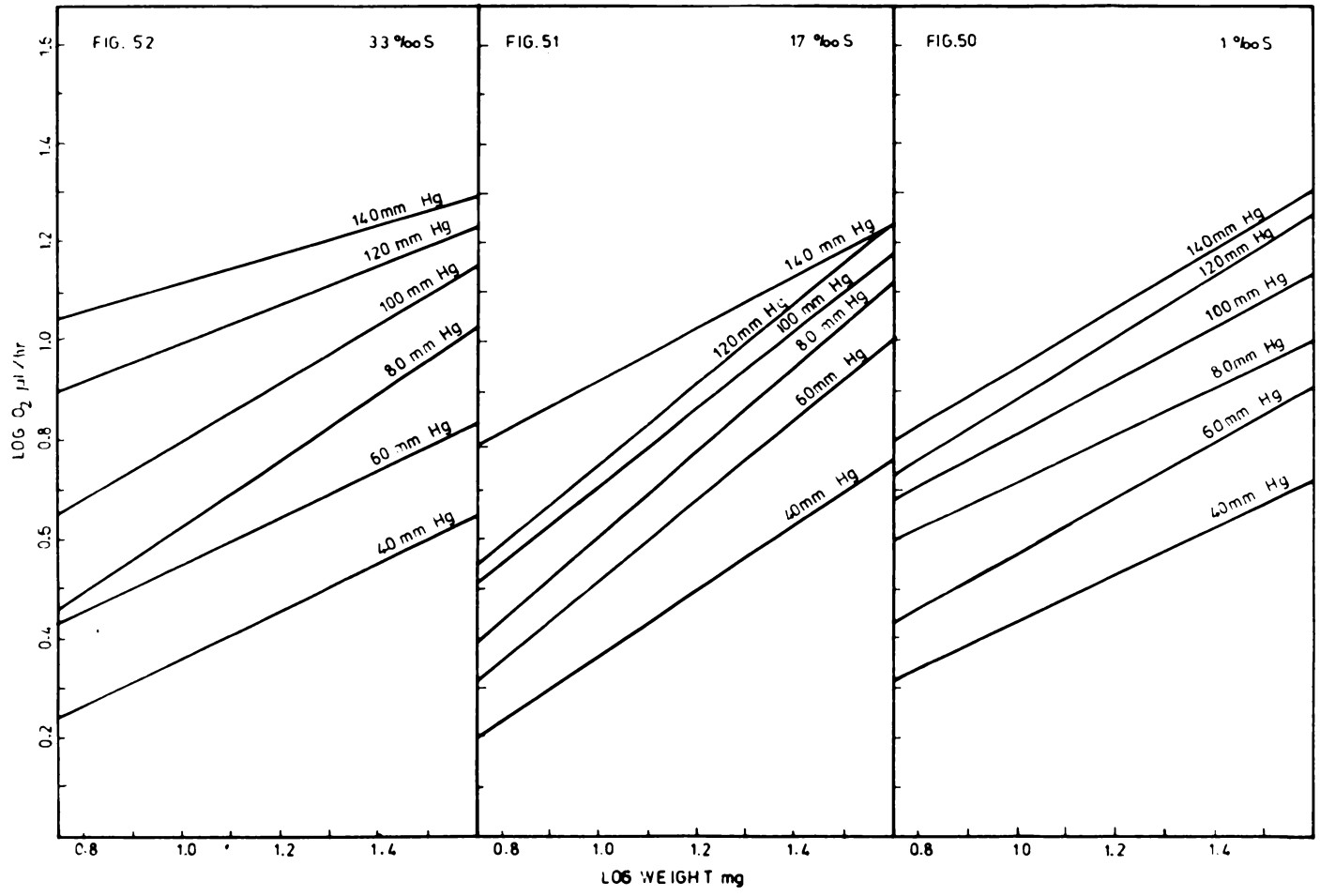


FIG. 52
33 ‰ S
FIG. 51
17 ‰ S
FIG. 50
1 ‰ S
140mm Hg
120 mm Hg
100 mm Hg
80 mm Hg
60 mm Hg
40 mm Hg
LOG O2 µl/hr
LOG WEIGHT mg
0.2
0.4
0.5
0.8
1.0
1.2
1.4
1.5
0.8
1.0
1.2
1.4

Table 82. Comparison of regression coefficients obtained for *C. willeyi* in declining $pO_2$ in the acclimation salinities.

| Comparing $pO_2$ mm Hg | Probability | | |
|---|---|---|---|
| | 1‰ S | 17‰ S | 33‰ S |
| 140 and 120 | N.S. | 0.01 - 0.02 | 0.02 - 0.05 |
| 140 and 100 | N.S. | 0.01 - 0.02 | < 0.001 |
| 140 and 80 | N.S. | 0.001- 0.01 | < 0.001 |
| 140 and 60 | N.S. | 0.001- 0.01 | 0.02 - 0.05 |
| 140 and 40 | N.S. | N.S. | 0.01 - 0.02 |
| 120 and 100 | N.S. | N.S. | 0.001-0.01 |
| 120 and 80 | 0.02 - 0.05 | N.S. | < 0.001 |
| 120 and 60 | N.S. | N.S. | N.S. |
| 120 and 40 | N.S. | N.S. | 0.02 - 0.05 |
| 100 and 80 | N.S. | N.S. | N.S. |
| 100 and 60 | N.S. | N.S. | N.S. |
| 100 and 40 | N.S. | N.S. | N.S. |
| 80 and 60 | N.S. | N.S. | N.S. |
| 80 and 40 | N.S. | N.S. | N.S. |
| 60 and 40 | N.S. | N.S. | N.S. |

(N.S. = Not significant)

Table 83. Oxygen uptake and metabolic rate of *C. willeyi* of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 17‰ S from the acclimation medium of 1‰ S. (Values taken from Fig. 53)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 5.595 | 559.5 |
| | 20 | 8.023 | 401.2 |
| | 30 | 9.906 | 330.2 |
| 100 | 10 | 4.256 | 425.6 |
| | 20 | 6.627 | 331.4 |
| | 30 | 8.588 | 286.3 |
| 80 | 10 | 3.676 | 367.6 |
| | 20 | 5.451 | 272.3 |
| | 30 | 6.866 | 228.9 |
| 60 | 10 | 2.935 | 293.5 |
| | 20 | 4.368 | 218.4 |
| | 30 | 5.513 | 183.8 |
| 40 | 10 | 1.487 | 148.7 |
| | 20 | 2.895 | 144.8 |
| | 30 | 4.274 | 142.5 |

Table 84. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 33‰ S from the acclimation medium of 1‰ S. (Values taken from Fig. 54)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.957 | 595.7 |
| 120 | 20 | 9.046 | 452.3 |
| | 30 | 11. 55 | 385.0 |
| | 10 | 5.166 | 516.6 |
| 100 | 20 | 7.739 | 387.0 |
| | 30 | 9.802 | 326.7 |
| | 10 | 4.334 | 433.4 |
| 80 | 20 | 6.770 | 338.5 |
| | 30 | 8.788 | 292.9 |
| | 10 | 3.188 | 318.8 |
| 60 | 20 | 5.074 | 253.7 |
| | 30 | 6.658 | 221.9 |
| | 10 | 2.310 | 231.0 |
| 40 | 20 | 2.918 | 145.9 |
| | 30 | 3.345 | 111.5 |

Table 85. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 1‰ S from the acclimation medium of 17‰ S. (Values taken from Fig.55)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 4.404 | 440.4 |
| 120 | 20 | 8.347 | 417.4 |
| | 30 | 12. 14 | 404.7 |
| | 10 | 3.400 | 340.0 |
| 100 | 20 | 6.494 | 324.7 |
| | 30 | 9.479 | 316.0 |
| | 10 | 2.724 | 272.4 |
| 80 | 20 | 5.514 | 275.7 |
| | 30 | 8.332 | 277.7 |
| | 10 | 2.124 | 212.4 |
| 60 | 20 | 4.422 | 221.1 |
| | 30 | 6.790 | 226.3 |
| | 10 | 1.558 | 155.8 |
| 40 | 20 | 3.044 | 152.0 |
| | 30 | 4.504 | 150.1 |

Table 86. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 33‰ S from the acclimation medium of 17‰ S. (Values taken from Fig. 56)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 5.736 | 573.6 |
| 120 | 20 | 8.247 | 412.4 |
| | 30 | 10. 20 | 340.0 |
| | 10 | 4.989 | 498.9 |
| 100 | 20 | 6.945 | 347.3 |
| | 30 | 8.428 | 280.9 |
| | 10 | 4.291 | 429.1 |
| 80 | 20 | 5.637 | 281.9 |
| | 30 | 6.613 | 220.4 |
| | 10 | 3.718 | 371.8 |
| 60 | 20 | 4.568 | 228.4 |
| | 30 | 5.153 | 171.8 |
| | 10 | 2.198 | 219.8 |
| 40 | 20 | 2.925 | 146.3 |
| | 30 | 3.457 | 115.2 |

Table 87. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 17‰ S from the acclimation medium of 33‰ S. (Values taken from Fig.57)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| | 10 | 7.485 | 748.5 |
| 120 | 20 | 10. 81 | 540.5 |
| | 30 | 13. 42 | 447.3 |
| | 10 | 6.272 | 627.2 |
| 100 | 20 | 9.383 | 469.2 |
| | 30 | 11.88 | 396.0 |
| | 10 | 4.576 | 457.6 |
| 80 | 20 | 8.002 | 400.1 |
| | 30 | 11. 10 | 370.0 |
| | 10 | 3.494 | 349.4 |
| 60 | 20 | 6.354 | 317.7 |
| | 30 | 9.016 | 300.5 |
| | 10 | 2.282 | 228.2 |
| 40 | 20 | 3.513 | 175.7 |
| | 30 | 4.520 | 150.7 |

Table 88. Oxygen uptake and metabolic rate of C. willeyi of standard weights 10, 20 and 30 mg in declining $pO_2$ when transferred to 1‰ S from the acclimation medium of 33‰ S. (Values taken from Fig. 58)

| $pO_2$ mm Hg | Body weight mg | $O_2$ uptake µl/h | Metabolic rate $O_2$ µl/g/h |
|---|---|---|---|
| 120 | 10 | 3.897 | 389.7 |
| | 20 | 7.499 | 375.0 |
| | 30 | 11.00 | 366.7 |
| 100 | 10 | 2.156 | 215.6 |
| | 20 | 5.403 | 270.2 |
| | 30 | 9.247 | 308.2 |

Table 89. Regression coefficients and their standard errors in declining $pO_2$ of C. willeyi under variations in salinity. n = number of experiments; b = regression coefficient; $S_b$ = standard error of b

| Accl. Sal. ‰ | Exp. Sal. ‰ | | $pO_2$ mm Hg 140 | 120 | 100 | 80 | 60 | 40 |
|---|---|---|---|---|---|---|---|---|
| 1 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.5867 | 0.5199 | 0.6389 | 0.5688 | 0.5738 | 0.9612 |
| | | $S_b$ | 0.0671 | 0.0599 | 0.0480 | 0.0817 | 0.0822 | 0.0925 |
| 1 | 33 | n | 17 | 17 | 17 | 17 | 17 | 17 |
| | | b | 0.6150 | 0.6030 | 0.5830 | 0.6436 | 0.6697 | 0.3370 |
| | | $S_b$ | 0.0542 | 0.0548 | 0.0639 | 0.0872 | 0.0974 | 0.1029 |
| 17 | 1 | n | 15 | 15 | 15 | 15 | 15 | 15 |
| | | b | 0.7828 | 0.9221 | 0.9332 | 1.0175 | 1.0576 | 0.9663 |
| | | $S_b$ | 0.0735 | 0.0774 | 0.0857 | 0.0878 | 0.0986 | 0.1209 |
| 17 | 33 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.4158 | 0.5238 | 0.4774 | 0.3935 | 0.2970 | 0.4123 |
| | | $S_b$ | 0.0372 | 0.0521 | 0.0514 | 0.0519 | 0.0699 | 0.0803 |
| 33 | 17 | n | 18 | 18 | 18 | 18 | 18 | 18 |
| | | b | 0.4628 | 0.5315 | 0.5811 | 0.8063 | 0.8627 | 0.6220 |
| | | $S_b$ | 0.0535 | 0.0597 | 0.0473 | 0.1386 | 0.1294 | 0.1353 |
| 33 | 1 | n | 14 | 14 | 14 | - | - | - |
| | | b | 0.7437 | 0.9441 | 1.3252 | - | - | - |
| | | $S_b$ | 0.0731 | 0.1344 | 0.3740 | - | - | - |

## PLATE 12

Figs. 53–58. Relationships between oxygen uptake(µl/h) and body weight of C. *willeyi* in declining oxygen tension ($pO_2$) when subjected to salinity changes.

PLATE 12

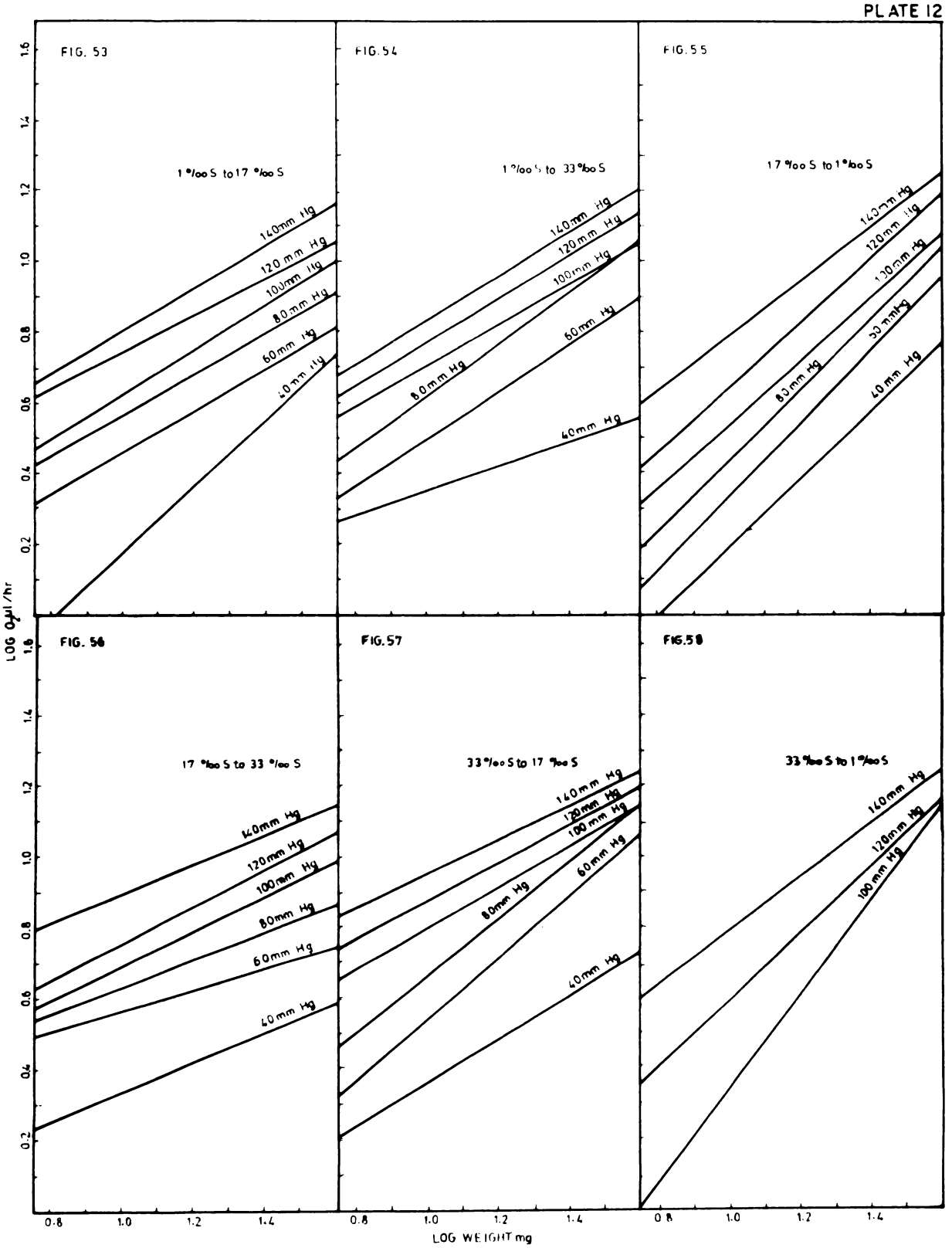


FIG. 53
1 °/oo S to 17 °/oo S
140mm Hg
120 mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 54
1 °/oo S to 33 °/oo S
140mm Hg
120 mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 55
17 °/oo S to 1 °/oo S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60 mmHg
40 mm Hg
FIG. 56
17 °/oo S to 33 °/oo S
140mm Hg
120mm Hg
100mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 57
33 °/oo S to 17 °/oo S
140mm Hg
120mm Hg
100 mm Hg
80mm Hg
60mm Hg
40mm Hg
FIG. 58
33 °/oo S to 1 °/oo S
140mm Hg
120mm Hg
100 mm Hg
LOG O2µl/hr
LOG WEIGHT mg
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.8
1.0
1.2
1.4

Table 90. Comparison of regression coefficients obtained for *S. willeyi* in declining $pO_2$ under variations in salinity.

| Comparing $pO_2$ mm Hg | Probability | | | | | |
|---|---|---|---|---|---|---|
| | Accl. Sal. 1‰ | | Accl. Sal. 17‰ | | Accl. Sal. 33‰ | |
| | Exp. Sal. 17‰ | 33‰ | Exp. Sal. 1‰ | 33‰ | Exp. Sal. 1‰ | 17‰ |
| 140 and 120 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 140 and 100 | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 140 and 80 | N.S. | N.S. | N.S. | N.S. | N.S. | 0.02–0.05 |
| 140 and 60 | N.S. | N.S. | 0.02–0.05 | N.S. | — | 0.001–0.01 |
| 140 and 40 | 0.001–0.01 | 0.02–0.05 | N.S. | N.S. | — | N.S. |
| 120 and 100 | N.S. | N.S. | N.S. | N.S. | — | N.S. |
| 120 and 80 | N.S. | N.S. | N.S. | N.S. | — | N.S. |
| 120 and 60 | N.S. | N.S. | N.S. | 0.01–0.02 | — | 0.02–0.05 |
| 120 and 40 | < 0.001 | N.S. | N.S. | N.S. | — | N.S. |
| 100 and 80 | N.S. | N.S. | N.S. | N.S. | — | N.S. |
| 100 and 60 | N.S. | N.S. | N.S. | 0.02–0.05 | — | 0.02–0.05 |
| 100 and 40 | 0.001–0.01 | N.S. | N.S. | N.S. | — | N.S. |
| 80 and 60 | N.S. | N.S. | N.S. | N.S. | — | N.S. |
| 80 and 40 | 0.001–0.01 | 0.02–0.05 | N.S. | N.S. | — | N.S. |
| 60 and 40 | 0.001–0.01 | 0.02–0.05 | N.S. | N.S. | — | N.S. |

(N.S. = Not significant)

Table 91. Average lethal levels of oxygen concentration for *S. annandalei*, *C. fluviatilis* and *C. willeyi* in various salinities.

| Species | Accl. Sal. ‰ | Exp. Sal. ‰ | $pO_2$ at the time of death mm Hg |
|---|---|---|---|
| *S. annandalei* | 1 | 1 | 10.93 |
| | 17 | 17 | 12.61 |
| | 33 | 33 | 13.68 |
| | 1 | 17 | 12.69 |
| | 1 | 33 | 9.56 |
| | 17 | 1 | 10.58 |
| | 33 | 17 | 8.73 |
| *S. fluviatilis* | 1 | 1 | 9.84 |
| | 17 | 17 | 11.35 |
| | 33 | 33 | 12.15 |
| | 1 | 17 | 8.14 |
| | 1 | 33 | 6.47 |
| | 17 | 1 | 6.60 |
| | 17 | 33 | 6.69 |
| | 33 | 17 | 11.09 |
| | 33 | 1 | 13.97 |
| *C. willeyi* | 1 | 1 | 9.61 |
| | 17 | 17 | 6.05 |
| | 33 | 33 | 8.12 |
| | 1 | 17 | 9.28 |
| | 1 | 33 | 12.77 |
| | 17 | 1 | 7.36 |
| | 17 | 33 | 7.43 |
| | 33 | 17 | 11.10 |
| | 33 | 1 | 75.93 |

## PLATE 13

Figs 59. Lower lethal levels of oxygen tension ($pO_2$) for *S. annandalei*, *C. fluviatilis* and *C. willeyi* in various salinities.

Fig. 60. Trend of variations in the rate of oxygen uptake of *S. annandalei* of standard weights 10, 20 and 30 mg. in various salinities.

A. acclimation salinity 1‰;
B. acclimation salinity 17‰ and
C. acclimation salinity 33‰

FIG.59

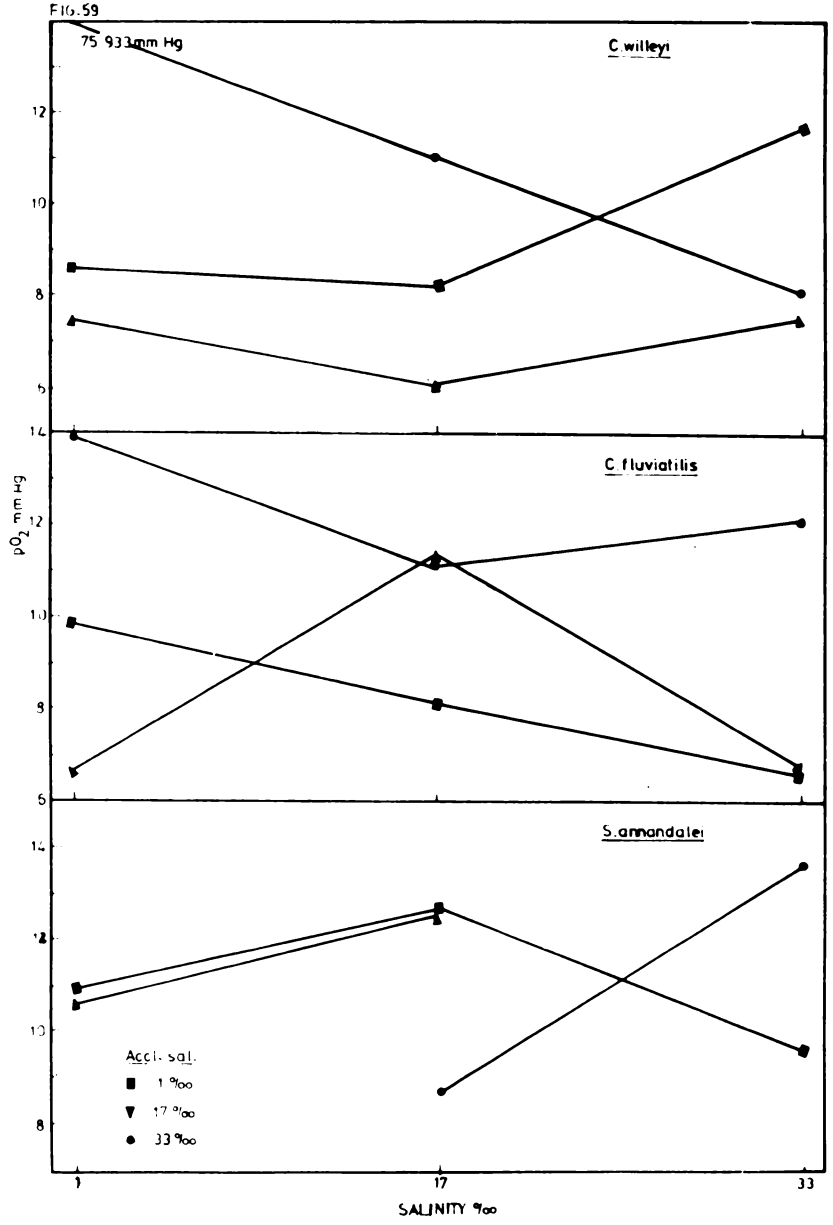
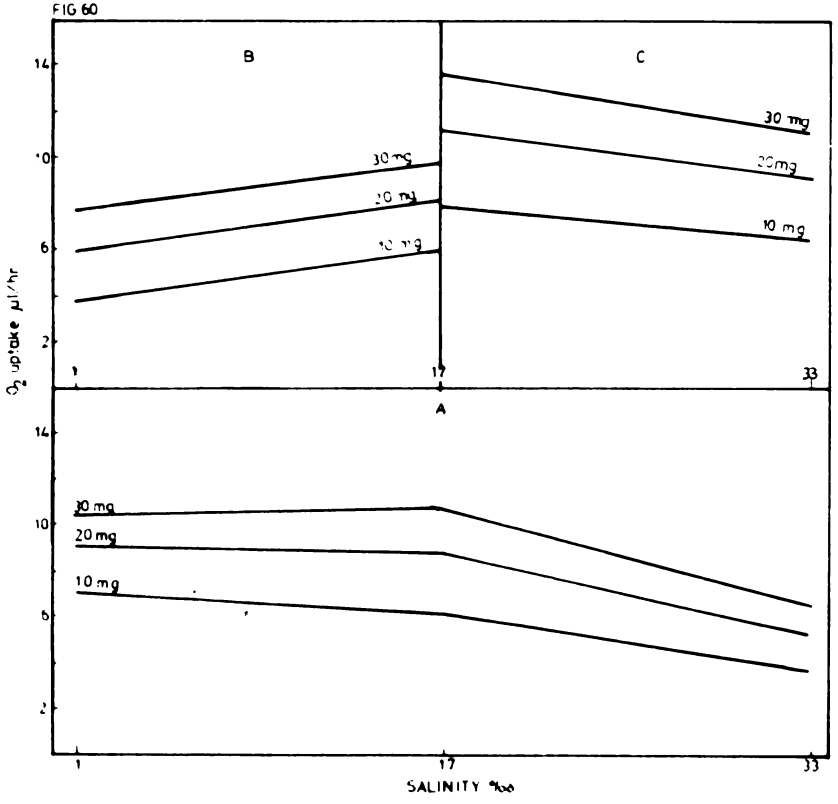

75 933mm Hg
C.willeyi
C.fluviatilis
S.annandalei
$pO_2$ mm Hg
Accl. sal.
1 ‰
17 ‰
33 ‰
SALINITY ‰

FIG 60


B
C
A
30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
SALINITY ‰

## PLATE 14

Fig. 61. Trend of variations in the rate of oxygen uptake of C. fluviatilis of standard weights 10, 20 and 30 mg. in various salinities.

A. acclimation salinity 1‰;
B. acclimation salinity 17‰ and
C. acclimation salinity 33‰.

Fig. 62. Trend of variations in the rate of oxygen uptake of C. willeyi of standard weights 10, 20 and 30 mg in various salinities.

A. acclimation salinity 1‰;
B. acclimation salinity 17‰ and
C. acclimation salinity 33‰.

FIG. 61

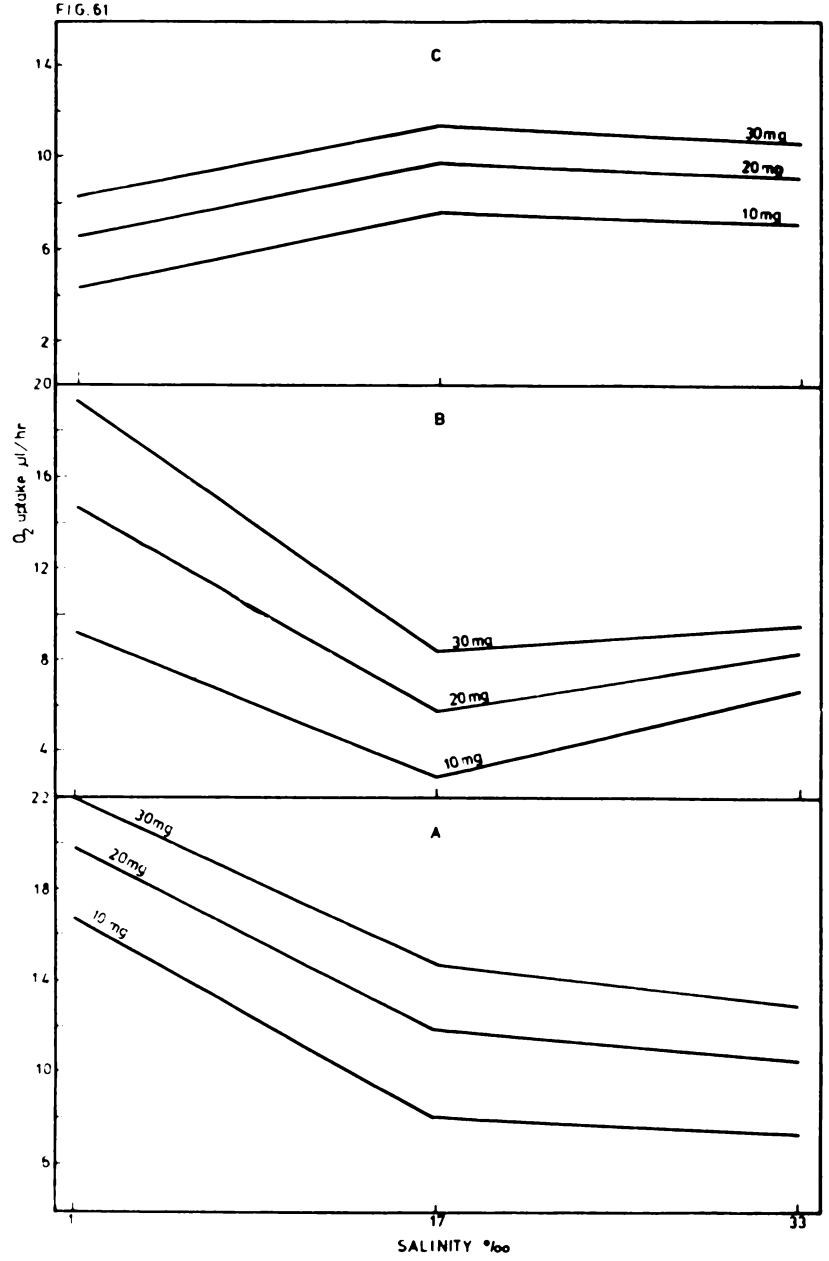
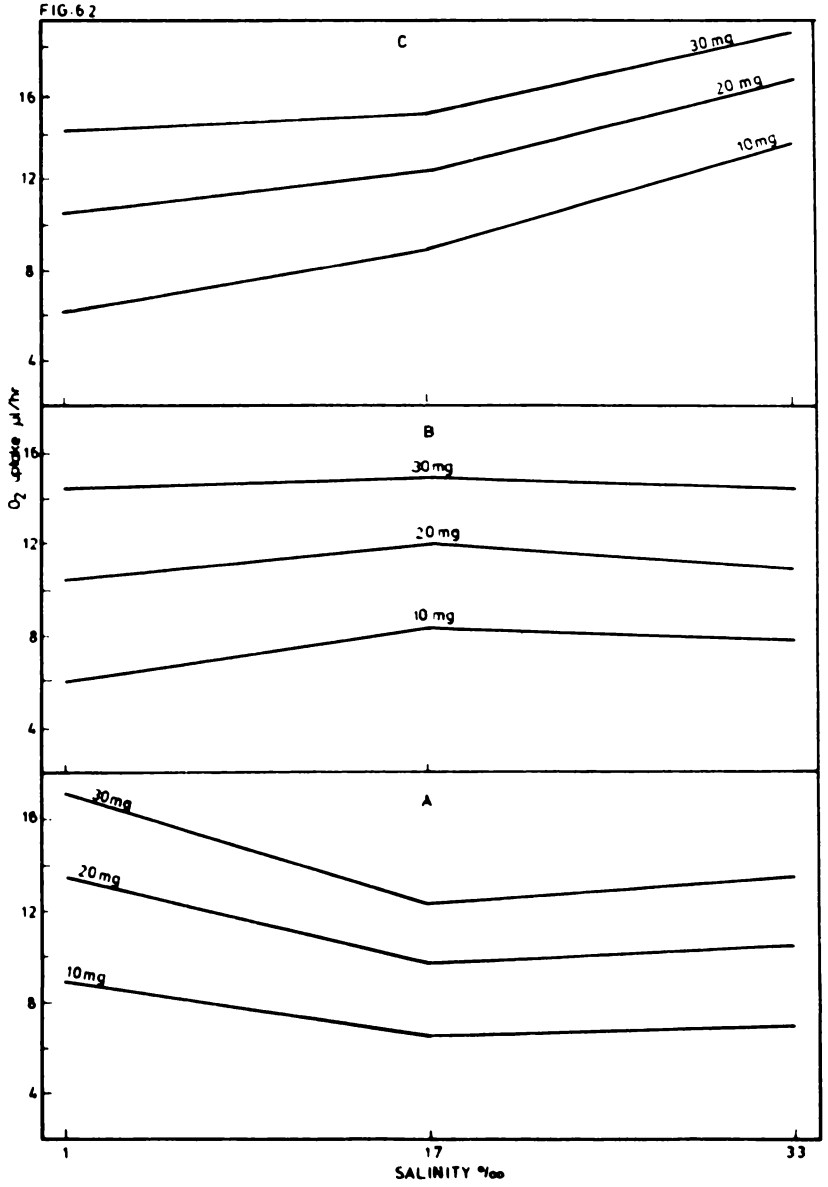

C
B
A
30mg
20mg
10mg
$O_2$ uptake µl/hr
SALINITY ‰
1
17
33

FIG. 62


C
B
A
30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
SALINITY ‰
1
17
33

## (iv) Discussion

### 1. Oxygen consumption in relation to body weight in the acclimation salinities

The oxygen uptake of whole individuals in all the three species increased with increasing body weight and the metabolic rate in terms of weight specific oxygen consumption ($O_2$ µl/g wet wt/h) showed a decline with the increase in body weight. It is well established that oxygen consumption is a power function of body weight and the biological significance of the regression coefficient ('b') has been discussed by various authors, as stated in the introduction to this chapter. The regression coefficients reported for crustaceans generally fall between 0.67 and 1.0, showing a range between surface area-related and weight related respiration (Wolvekamp and Waterman, 1960). A common value of 0.75 was suggested for poikilotherms by Hemmingsen (1960).

The regression coefficients reported here for *S. annandalei*, *C. fluviatilis* and *C. willeyi* in $pO_2$ 140 mm Hg in the acclimation salinities significantly differ from the above general value. In *S. annandalei* the values of 'b' obtained are 0.3423, 0.4457 and 0.4854, respectively in the acclimation media of 1, 17 and 33‰ S. The 'b' values for *C. fluviatilis* are 0.2495, 0.9173 and 0.3663 and for *C. willeyi* 0.5976, 0.5211 and 0.2815, respectively in 1,17 and 33‰ S. The 'b' values reported for various crustaceans by Ellenby (1951), Edney and Spencer (1955), Bertalanffy (1957), Roberts (1957), Subrahmanyam (1957, 1962), Barnes and Barnes (1959), Teal (1959), Ganapati and

Prasada Rao (1960), Small and Hebard (1967), Bulnheim (1974) etc. are between 0.67 and 1.0. But several others have reported instances of low 'b' values in crustaceans. Conover (1959) obtained values less than 0.67 for calanoid copepods. Dehnel (1960) reported 'b' values for the intertidal crabs Hemigrapsus oregonensis and H. nudus varying between 0.315 and 0.667 and stated that only very few values approached the generally known regression coefficients for crustaceans. For the prawns Metapenaeus monoceros and Penaeus indicus Rao (1958), Subrahmanyam (1962) and Kutty (1969) have reported values below 0.6. Newell and Northcroft (1965) have obtained low values for the barnacle Balanus balanoides. Values like 0.37 and 0.48 which are appreciably below the common range have been noticed by Haq (1967) for the copepods Metrida lucens and M. longa. Very low values ranging from 0.037 to 0.444 have been recorded for the amphipods Bathyporeia pilosa and B. pelagica by Fish and Preece (1970). Cheriyan (1973) obtained values as low as 0.3428 and 0.4463 for the wood-boring isopod Sphaeroma terebrans. In general the values of 'b' obtained in the present study for S. annandalei, C. fluviatilis and C. willeyi in the three acclimation salinities are much lower than would be expected on the basis of the common regression value of 0.75 suggested by Hemmingsen (1960). Instead, they correspond to the low regression coefficients reported by various authors cited above. It is interesting to note that the values obtained for S. annandalei conforms well with those reported by Cheriyan (1973) for S. terebrans which belongs to the same genus and found coexisting in the locality.

Tables 14, 38 and 66 show that for each species the values of 'b' are different in the three salinities studied. When these values are compared significant difference is found between the regression coefficients in 1 and 33‰ S for S. annandalei (Table 16). In C. fluviatilis the difference in 'b' is significant between 1 and 17‰ S and also between 17 and 33‰ S. (Table 40). A comparison of the values obtained for C. willeyi shows significant differences between 1 and 33‰ S and also between 17 and 33‰ S (Table 68). These variations in the relationship between oxygen consumption and body weight in the various acclimation salinities indicate that a single regression coefficient does not apply when making interspecific comparisons. Also, one regression coefficient does not indicate the metabolic response of a species under all conditions. Instances of variations in the weight regression in crustaceans have been reported by some authors. Rao and Bullock (1954) noticed that the weight regression in the amphipod Talorchestia megalopthalma was not a characteristic value for the species, but varied with season. Rao (1958) has shown that the 'b' value varies from 0.50 to 0.93 in a marine population of the prawn Metapenaeus monoceros according to salinity variations. Brackish water populations of this species also showed variations in the value of 'b' in various salinities and these values did not correspond with those obtained for M. monoceros from the marine population at comparable salinities. Vernberg and Costlow(1966) have reported seasonal variations in the regression coefficients of

the various stages of the fiddler crab Uca spp. Barnes and Barnes(1969) have reported marked variations in the relationship between metabolic rate and body weight in the barnacles Balanus balanoides, B. balanus and Chthamalus stellatus. Prasada Rao and Ganapati (1969) also have reported considerable differences in the metabolism - body size relationship in the barnacles Balanus amphitrite and B. tintinnabulum. These instances of variations in the weight regression in crustaceans are mainly attributed to seasonal changes in temperature, stage of life cycle etc. But as stated elsewhere, the habitat of the present three species of isopods is not subjected to considerable variations in temperature. Instead, the salinity shows wide variations on the basis of which three distinct hydrographical seasons could be recognised viz., the Monsoon season of very low salinity, the post-Monsoon season of medium salinity, and the pre-Monsoon season of high salinity. The present studies on the oxygen consumption of the animals in each of these three seasons under controlled temperature conditions reveal that the variations in the regression coefficients of these isopods are related to the seasonal changes in salinity. The view expressed by Newell and Pye (1971) that this type of variations in the relationship between body weight and oxygen consumption must reflect some more complex phenomenon whose influence may be superimposed upon the effects of aggregate cell surface area, is also pertinent in this context.

A comparison of the respiratory rates reported for other isopods with the present values is a difficult task since the experimental

techniques employed, factors studied, and the environmental history of the species concerned differ from each other. Reinders (1933) reported the metabolic rate ($O_2$ µl/g wet wt./h) of the woodlouce Porcellio scaber as 147.5 at 16°C, while Newell et al (1974) found it to be varying between 106.9 and 257.4 at 15°C. They also reported that at 25-30°C, the metabolic rate of P. scaber was between 209.1 and 491.2 µl/g/h. In Idotea neglecta the rate is reported to be varying between 153 and 321 µl (Fox and Simmonds, 1933). Wolvekamp and Waterman (1960) have given the respiratory rate of Asellus aquaticus as to be varying between 505 and 863 µl at 10°C. Muller (1943) obtained the respiratory rate of Armadillidium pallasii as 105 µl at 21°C. In Oniscus asellus the respiratory rate is reported to be varying between 120 and 348 µl (Edwards, 1946; Edney and Spencer, 1955; Phillipson and Watson, 1965). In Ligia oceanica at 25°C the rate falls between 179 and and 400 µl (Ellenby, 1951), and at 22°C it is 192 µl (Edney and Spencer, 1955). The respiratory rate reported for Naesa bidentata by Wieser(1962) varied between 215 and 695 µl. Frankenberg and Burbanck (1963) obtained metabolic rates for Cyathura polita varying between 89 and 98 µl (converted from dry weight data) at 15°C. Schachter (1964) found the respiratory rates in Sphaeroma hookeri to be within the range of 100 to 400 µl. For Limnoria spp. Eltringham (1965) has reported the respiratory rates as 185.3 µl at 25°C and 125.3 µl (converted from dry weight data) at 20°C. Nagabhushanam and Gopalakrishnamurthy (1965 a) obtained values between 92 and 226 µl for Cirolana fluviatilis in various salinities. The metabolic rate of Sphaeroma terebrans is reported to be varying

between 169.1 and 410.2 µl in 5‰S and between 242.8 and 1134.0 µl in 20‰S by Cheriyan (1973). For three species of Idotea, Jones (1974) has reported the metabolic rate to be varying between 50.8 and 113.0 µl (converted from dry weight data) at 8°C.

In the present studies the metabolic rates obtained for S. annandalei, (10 - 60 mg wet weight) vary from 221.5 to 720.2 µl $O_2$/g/h in 1‰S, from 224.2 to 604.9 in 17‰S and from 263.7 to 663.0 in 33‰S (Table 15). In C. fluviatilis (10 - 30 mg) it ranges between 730.7 and 1666.0 in 1‰S, between 280.4 and 307.0 in 17‰S and between 353.0 and 708.1 in 33‰S (Table 39). The metabolic rates of C. willeyi (10 - 30 mg) in 1‰S are between 572.0 and 889.8, in 17‰S between 497.3 and 841.6 and in 33‰S between 605.7 and 1333.0 (Table 67). These values are mostly high compared to those reported for other isopods. The metabolic rates reported by Cheriyan (1973) for Sphaeroma terebrans, a closely allied species to S. annandalei show a wider range than that of the latter. However, the lower limit is only slightly lower than that of S. annandalei while the higher limit is far higher than that of the latter. This shows that the metabolic rates of larger animals in both species are comparable while those of the smaller ones differ considerably.

Table 15 shows that the metabolism of small sized animals (10 mg group) varies widely in the three salinities than that of big sized ones (60 mg group) in S. annandalei. In fact the differences in the respiratory rates of animals of 60 mg are not considerable in the three media.

Therefore, it can be assumed that the metabolic rate of comparatively young animals is more affected by the seasonal variations in the salinity. However, the average metabolic rates of S. annandalei do not show considerable variations according to the seasonal changes in salinity (Table 15).

It has been observed that many aquatic invertebrates respire at most economic rates in salinities to which they are genetically adjusted (Kinne, 1971). Also, studies by several authors have revealed that the respiratory rate of euryhaline crustaceans changes under conditions of osmotic stress mostly as an increase under adverse conditions (Schwabe, 1933; Lofts, 1956; Lance, 1965; Hagerman, 1969, 1970). According to these views it seems that S. annandalei is better adjusted to live in medium salinity, as the slight differences in the average metabolic rates reveal. Of the other two acclimation media, the low salinity is preferred by S. annandalei. These findings agree well with the conclusions made while discussing the salinity tolerance of the species (Chapter III). However, the variations in the average metabolic rates of this species in the three salinities being not so prominent, it can be assumed that the animal is not under considerable stress in any of the three seasons.

The metabolic rates of Cirolana spp. are higher than that of S. annandalei. Cirolana spp. are free moving and very active while S. annandalei is leading a relatively sedentary life in its burrow in

the wood. Perhaps this difference in the activity accounts for the differences in the metabolic rates of these isopods. Moshiri et al. (1969) and Coull and Vernberg (1970) have observed such correlations with activity in some crustaceans.

Unlike S. annandalei, both the big sized and small sized ones in Cirolana spp. show considerable variations in the metabolic rate in relation to the seasonal changes in salinity (Table 39 and 67). Similar to S. annandalei, both C. fluviatilis and C. willeyi respire at the minimum rate in the medium salinity and this suggests that they are genetically better adjusted to it. Of the other two acclimation salinities, the maximum rate of C. fluviatilis is in the low salinity while that of C. willeyi is in the high salinity. This means that the former prefers the high salinity to the low salinity while the latter prefers the low salinity. The average metabolic rate of C. willeyi in the low salinity is much less than that of C. fluviatilis (Tables 39 and 67). This reflects the capacity of C. willeyi to tolerate very low salinities with less stress compared to the other species.

Thus in terms of the generalisations that organisms respire at most economic rates in the salinities to which they are genetically adjusted (Kinne, 1971) and that the respiratory rate increases under adverse conditions (Hagerman, 1970) the present findings agree with the results of the studies on the salinity tolerance of these isopods.

2. Oxygen consumption in relation to variations in salinity and body weight

The oxygen uptake of S. annandalei, C. fluviatilis and C. willeyi in abruptly changed salinities is markedly weight dependent and the metabolic rate falls off rapidly with increasing body weight, as is found in the acclimation salinities. Also, the regression coefficients of oxygen uptake against body weight show significant variations under several changed salinities. Assessing the literature available only few papers on the respiratory metabolism of isopods contain information on the relationship between $O_2$ uptake and body weight in relation to changes in salinity. Cheriyan (1973) and Bulnheim (1974) have reported the regression coefficients obtained for Sphaeroma terebrans and Idotea balthica, respectively, under salinity variations.

The regression coefficients obtained for S. annandalei vary from 0.4993 to 0.6430, when subjected to salinity variations. The minimum value of this range is not statistically different from the minimum value obtained in the acclimation salinities (Table 23). But the maximum value is significantly higher than that obtained in the acclimation salinities. This shows that the extent of variation in the regression coefficients increases under direct salinity changes in S. annandalei.

The regression coefficients of C. fluviatilis in the changed salinities vary between 0.3067 and 0.6636. Table 49 shows that this range is not significantly different from that obtained in the acclimation salinities. In C. willeyi the regression coefficients under variations

in salinity range between 0.4158 and 0.7828. The minimum value of this range is significantly higher than that in the acclimation salinities. But the maximum values are not statistically different from each other (Table 77).

In S. annandalei the regression values obtained when animals acclimated in 1‰ S are transferred to 17‰ S and 33‰ S, do not significantly vary from each other. But they are higher than the value in the acclimation salinity (Table 23). In C. fluviatilis also significant higher 'b' values are obtained when animals acclimated in 1‰ S are transferred to higher salinities (Table 49). The correlation coefficients ('r') given in Table 22 and 48 indicate that the metabolism - body weight relationship becomes more prominent in the above instances. When C. willeyi acclimated in 1‰ S and 17‰ S are transferred to the higher salinities the 'b' values obtained are not significantly different from those obtained in the acclimation salinities (Table 77). But the correlation coefficients (Table 76) show that the weight relation in general is more pronounced in these changed salinities. However, this generalisation does not apply to C. fluviatilis transferred to 33‰ S from the acclimation medium of 17‰ S, where a significant lower 'b' value is obtained. It is also noteworthy that in each of the three species, no significant differences exist between the 'b' values obtained in the medium and high salinities, when they are transferred from the low salinity. This shows that the amount of variation in the weight regression, if any, is almost the same in the above cases. But when

C. fluviatilis and C. willeyi acclimated in the low salinity are transferred to the medium salinity and those acclimated in the medium salinity are transferred to the high salinity, the 'b' values obtained differ from each other in each species indicating different amounts of variation in the relationship. Similar is the case of the values obtained when the above species acclimated in the low salinity and those acclimated in the medium salinity are transferred to the high salinity. In S. terebrans Cheriyan (1973) observed no significant differences between the 'b' values obtained when changed to higher salinities. In this respect C. willeyi resembles S. terebrans though the salinities used in both the cases are not exactly similar. But the observation of Bulnheim (1974) that in Idotea balthica the 'b' value increases when animals acclimated in a low salinity are transferred to a high salinity, agrees with the present findings on S. annandalei and C. fluviatilis.

When the present species are transferred from higher salinities to lower salinities, the metabolism - weight relationship varies with species in the respective salinities (Table 23, 49 and 77). Thus in S. annandalei and C. fluviatilis, the 'b' values in the acclimation salinity of 33‰ does not vary significantly from that obtained when the animal is transferred to 17‰ S. But when S. annandalei acclimated in 17‰ S is transferred to 1‰ S, the 'b' value is significantly higher compared to that obtained in the acclimation medium. In identical case, the 'b' value of C. fluviatilis does not show signifcant variation. But the value obtained when C. fluviatilis acclimated in 33‰ S is transferred

to 1‰ S, is significantly higher than that in the acclimation medium. In the case of C. willeyi high values are obtained in all the cases when the salinity of the experimental medium is lower than that of the acclimation medium. A generalisation applying to all the three species is difficult, based on these observations. However, it can be noticed that in the case of S. annandalei, the 'b' value increases only when the salinity is decreased from 17‰ S to 1‰ S. In the case of C. fluviatilis significant higher value is obtained when the animals acclimated to the high salinity are transferred to the lowest salinity indicating that the value differs only when the amount of salinity variation is very high. But in C. willeyi the regression values increase in all cases when animals are transferred to salinities lower than the acclimation salinities. Cheriyan (1973) has observed significant increase in the 'b' values when S. terebrans was transferred to lower salinities like 10 and 1‰ from the acclimation medium of 20‰ S.

No significant differences between the regression coefficients of S. terebrans have been noticed by Cheriyan (1973) in lower salinities like 10, 5 and 1‰ when animals were transferred from the acclimation medium of 20‰ S. But in the present study, in each of the three species, significant variations are seen between the 'b' values obtained when animals acclimated in the high salinity are transferred to the medium salinity and those acclimated in the medium salinity are transferred to the low salinity. This is also true for C. fluviatilis and C. willeyi when they are transferred to the medium and low salinities from the acclimation medium of 33‰ S. However, no significant differences are

observed between the 'b' values obtained for animals acclimated to the high salinity (33‰S) and changed to the low salinity (1‰S) and the 'b' values obtained for animals acclimated to the medium salinity (17‰S) and changed to the low salinity (1‰S), for both species of Cirolana.

A comparison of the 'b' values obtained for each of the three species in the acclimation salinity with the 'b' values obtained in the same salinity when animals acclimated in other salinities are transferred to it, reveals various trends. Thus the 'b' value obtained in 1‰S for S. annandalei acclimated in 17‰S is higher than that obtained for animals in the acclimation salinity of 1‰. But for this species, in 17‰S the 'b' values are not significantly different from each other. Similar is the trend in 33‰S also. For C. fluviatilis in 1‰S, the values obtained are significantly different. But the values of animals acclimated in 17‰S and 33‰S when transferred to 1‰S do not differ significantly from each other. In 17‰S all the values vary significantly from each other. But in 33‰S no significant difference is seen. The 'b' value of animals acclimated in 1‰S differ from that obtained for animals acclimated in 17‰S, when both are transferred to 33‰S. In the case of C. willeyi no significant changes in the 'b' value are seen in 1‰S and 17‰S. But the values differ in 33‰S according to the differences in acclimation salinities.

It has been established that sublethal variations in salinity may modify the rate of metabolism of aquatic invertebrates (Kinne, 1971).

Table 21 shows that the metabolic rates of S. annandalei of weights 10-60 mg vary between 802.8 and 155.1 µl $O_2$/g/h when animals are subjected to salinity variations. The average metabolic rate when animals acclimated in 1‰ S are transferred to 17‰ S, is not different from that obtained in the acclimation salinity. When animals acclimated in 1‰ S are transferred to 33‰ S, the average rate considerably decreases. Also, when animals acclimated in 17‰ S are transferred to the lower salinity the average metabolic rate decreases. But when animals acclimated in 33‰ S are transferred to 17‰ S, there is an increase in the metabolic rate. On the whole, not considering the slight decrease in the average metabolic rate when animals acclimated in 17‰ S are transferred to 1‰ S, it can be stated that the $O_2$ uptake of S. annandalei decreases in supranormal salinity while it increases in subnormal salinity (Fig. 60). Cheriyan (1973) reported a decrease in the respiratory rates of S. terebrans in supra- and subnormal salinities. But Jones (1974) observed that the respiratory rates of Idotea chelipes, a brackish water isopod, remain essentially unaffected in subnormal salinities. Frankenberg and Burbanck (1963) and Eltringham (1965) also have noticed constant respiratory rates in some euryhaline isopods when subjected to salinity variations. But Jones (1974) found that the marine isopods Idotea neglecta and I. emarginata show an increase in respiration, followed by a slight fall at reduced salinities. But Nagabhushanam and Gopalakrishnamurthy (1965 a) have reported increased metabolic rates for C. fluviatilis in subnormal salinities, as noticed in the present observation. Even though the metabolic responses of

S. annandalei differ from most of those reported for other isopods, several euryhaline crustaceans other than isopods have been reported to be exhibiting such reactions to salinity stress (Kinne, 1971).

In C. fluviatilis the metabolic rates vary between 931.1 and 277.5 µl $O_2$/g/h for 10 - 30 mg animals in the changed salinities. Table 47 shows that in general, the average metabolic rates decrease in supranormal salinities while they increase in subnormal salinities. Exceptions to this generalisation are seen in animals transferred to 33‰S from 17‰S where an increase in the rate is observed, and in those transferred to 1‰S from 33‰S where a decrease is noticed. Not considering these exceptions, the metabolic responses of C. fluviatilis are similar to those of S. annandalei, under salinity variations (Fig.61). It is noteworthy that the increase of metabolic rates in subnormal salinities has been observed also by Nagabhushanam and Gopalakrishnamurthy (1965 a) in C. fluviatilis, even though the rates reported by them are very low compared to the present data.

The metabolic rates of C. willeyi vary between 890.4 and 412.3 µl $O_2$/g/h in 10 - 30 mg animals under salinity variations (Table 75). The $O_2$ uptake in this species shows a decrease in both supra - and subnormal salinities (Fig.62). This type of response to salinity stress is usually found only in stenohaline forms which suffer from osmotic damage whenever the salinity variations occur (Kinne, 1971). But the observation of Cheriyan (1973) on the euryhaline isopod Sphaeroma terebrans agrees with the present finding on C. willeyi.

Based on the respiratory rates of S. terebrans under variations in salinity, Cheriyan (1973) reported that the capacity to withstand adverse conditions is proportionate to size, i.e., as the size of the animal increases, the capacity for tolerance decreases. But a perusal of the present data shows that in these three isopods, the small animals are more affected by salinity stress as indicated by the variations in the respiratory rates.

Experiments on the salinity tolerance (Chapter III) showed that when S. annandalei is abruptly transferred to 33‰ S from the acclimation medium of 1‰ S there was only 20% survival after the 10 days, indicating the high degree of osmotic stress involved. Similarly, when animals were changed to 1‰ S from 17‰ S only 80% survived for 10 days, showing some stress in the changed medium. (In all the other media there was 100% survival). The variations in the average metabolic rates of S. annandalei in the above mentioned salinity changes conform these observations. There is a considerable decrease in the average metabolic rate when animals acclimated in 1‰ S are directly transferred to 33‰ S and the decrease is less when animals are changed to 1‰ S from 17‰ S. In C. fluviatilis, the survival was only 60% when animals acclimated in in 17‰ S were transferred to 1‰ S and only 20% when animals acclimated in 33‰ S were transferred to 1‰ S. The present observations on the metabolic rates reveal a considerable increase in the former case and a decrease in the latter. In C. willeyi, the survival was only 70% and 20% respectively in the above salinity variations. Here, in both

the cases of salinity variation, a decrease in the metabolic rates is noticed. The decrease is much in the latter case in which only 20% survival was noticed after 10 days.

Even though the variations in the metabolic rate indicate the osmotic stress which is conformed by the low percentage of survival in the salinity tolerance experiments, it appears that they do not yield a general clue for analysing the capacity of these euryhaline isopods to resist the effects of salinity variations.

3. Oxygen consumption in declining oxygen tension

The oxygen consumption in S. annandalei, C. fluviatilis and C. willeyi is weight dependent in declining oxygen tension also. Statistical analysis (Tables 28, 54 and 82) shows that in general the regression coefficients do not vary significantly in declining oxygen tension in the acclimation media of 1 and 17‰ S for each of the three species. But in 33‰ S a significant increase in the 'b' value is noticed when the $pO_2$ is reduced to 60 mm Hg in S. annandalei. For C. fluviatilis it becomes significantly high when the $pO_2$ is reduced to 100 mm Hg in 33‰ S. But further significant increase is not noticed in the above cases. For C. willeyi the 'b' value in 33‰ S increases steadily till the $pO_2$ is reduced to 100 mm Hg. There is no increase when the $pO_2$ is reduced further. Studies on the effect of ambient oxygen tension on the metabolism - body size relationship are few for comparisons. Cheriyan (1973) observed no significant differences in the 'b' values of S. terebrans in various salinities.

In most cases of abrupt changes in salinity also, the regression coefficients do not vary significantly (Tables 34, 62 and 90). In S. annandalei a significant increase in the 'b' value is noticed as the $pO_2$ is reduced to 100 mm Hg when the animals acclimated in 1‰ S are transferred to 17‰ S. Further increase is not noticed under still lower oxygen tensions. In the same salinity the regression coefficient of C. willeyi also becomes high as the $pO_2$ goes down to 40 mm Hg. When S. annandalei acclimated in 17‰ S is transferred to 1‰ S the regression coefficient increases as the $pO_2$ declines to 60 mm Hg. There is no further increase in this case also. In C. fluviatilis and C. willeyi when specimens acclimated in 33‰ S are transferred to 17‰ S, significant increase in the 'b' value is seen in 100 and 80 mm Hg, respectively. Significant decrease in the regression value is noticed when the $pO_2$ reaches 40 mm Hg in the case of C. willeyi which is transferred to 33‰ S from the acclimation medium of 1‰ S. Since the variations in the 'b' values due ~~are~~ to the influence of declining oxygen tension are not evident in majority of the experiments, it can be concluded that $O_2$ tension is not a major factor which influences the metabolism- body size relationship of these isopods.

Investigations have been carried out by various authors on the relation between external oxygen tension and the rate of oxygen uptake on the basis of which aquatic animals are classified into two categories as mentioned in the introduction: (i) conformers, in which the oxygen consumption is dependent on oxygen tension; and (ii) regulators in which the respiratory rate is constant over a certain range of oxygen tensions

until some critical tension is reached and then the rate declines rapidly (Wolvekamp and Waterman, 1960; Prosser and Brown, 1961; Lockwood, 1967; Vernberg and Vernberg, 1972). Both the types are met with in crustaceans. Figs. 63, 66 and 68 show that the oxygen uptake of S. annandalei is constant between $pO_2$ 140 and 100 mm Hg in the three acclimation salinities. The critical tension in these salinities is between 100 and 80 mm Hg. The critical tension shifts to between 120 and 100 mm Hg, thereby narrowing the zone of independent oxygen uptake, when S. annandalei acclimated in 1 or 17‰ S is transferred to the other salinities (Figs. 64, 65 and 67). In these cases the animal is a regulator. Even though the critical tension of the regulators varies with species, the values reported here for S. annandalei are high compared to those of other crustaceans, in general. In the crab Pugettia producta the critical tension is at about 50 - 70 mm Hg (Weymouth et al, 1944) and in the crayfish Orconectes virilis it is lower than 40 mm Hg (Hiestand, 1931). In the shrimps Upogebia pugettensis and Callianassa californiensis it is 45 - 55 and 10 - 20 mm Hg, respectively (Pritchard and Kasparek, 1966). But Cheriyan (1973) found Sphaeroma terebrans to be a regulator whose critical tension is 100 mm Hg and this value is in general agreement with the present findings. However, S. annandalei becomes a conformer when transferred to 17‰ S from the acclimation medium of 33‰ S (Fig.69).. Such cases where a regulator becomes a conformer under certain instances of salinity stress point to the fact that there is no absolute distinction between regulators and conformers. Instances of regulators becoming conformers and vice versa have been reported by Maloeuf (1937) and Wiens and Armitage (1961) also.

## TABLE 15

Figs. 63–69. Trend of variations in the rate of oxygen uptake of *S. annandalei* of standard weights 10, 20, 30, 40, 50 and 60 mg in declining $pO_2$ in various salinities.

Fig. 63. 1‰ S; Fig.64 1‰ S to 17‰ S; Fig.65 1‰ S to 33‰ S; Fig. 66. 17‰ S; Fig.67. 17‰ S to 1‰ S; Fig.68. 33‰ S and Fig. 69. 33‰ S to 17‰ S.

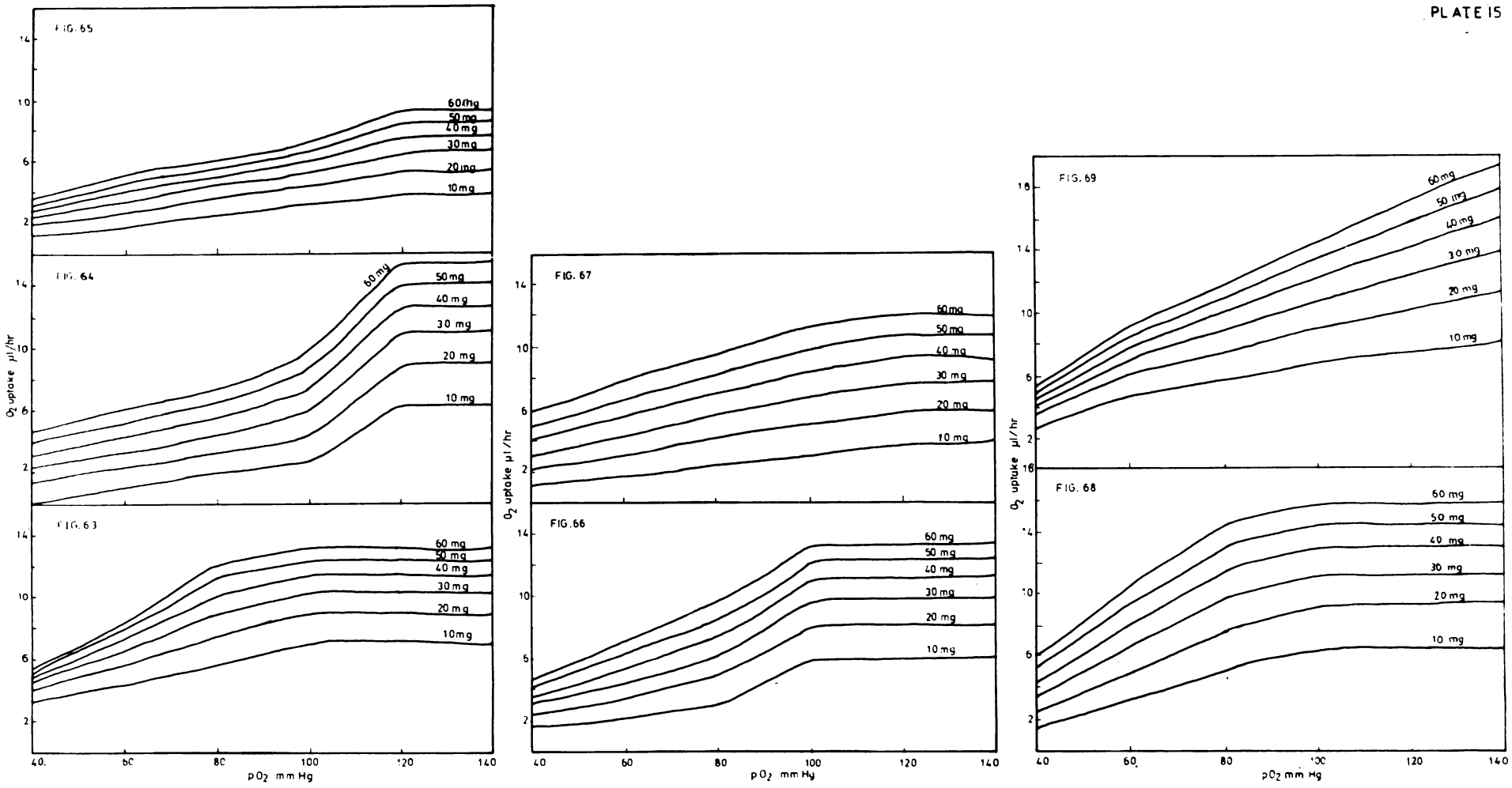


FIG. 65
60mg
50mg
40mg
30mg
20mg
10mg
FIG. 64
60 mg
50 mg
40 mg
30 mg
20 mg
10 mg
FIG. 63
60 mg
50 mg
40 mg
30 mg
20 mg
10mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg
FIG. 67
60mg
50mg
40 mg
30 mg
20 mg
10 mg
FIG. 66
60 mg
50 mg
40 mg
30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg
FIG. 69
60 mg
50 mg
40 mg
30 mg
20 mg
10 mg
FIG. 68
60 mg
50 mg
40 mg
30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg

C. fluviatilis and C. willeyi are conformers in which oxygen uptake decreases with the declining oxygen tension (Figs. 70 - 87). Dependence of oxygen tension has been reported in Homarus americanus, Limulus polyphemus, Callinectes sapidus, Penaeus indicus, Menippe mercenaria, Panopeus herbstii etc.(Amberson et al, 1924; Maloeuf, 1937 a; Thomas, 1954; Subrahmanyam, 1962; Leffler, 1972, 1973).

In a few cases the metabolic rates of larger animals exceed those of smaller ones in declining $pO_2$ and hence the regression coefficients in these cases become higher than 1.0, in the present study. Thus in C. fluviatilis the larger animals have higher metabolic rates in declining $pO_2$ in the acclimation medium of 17‰ S. Similarly in C. willeyi the larger animals have a higher rate than the smaller ones when transferred to 1‰ S from 33‰ S as the $pO_2$ is reduced to 100 mm Hg from 120 mm Hg. Larger animals of C. willeyi also show higher metabolic rates from 100 mm Hg downwards when transferred to 1‰ S from 17‰ S.

The differences observed in the responses to decreasing oxygen tension of S. annandalei and Cirolana spp. may be attributed to the differences in their habits. S. annandalei being a wood-borer rarely moves out of the burrow and hence is comparatively sedentary in habit, as stated elsewhere. This necessitates some amount of regulation of the respiratory rates. But the range of independent $O_2$ uptake is comparatively narrow, the critical oxygen tension being around 100 mm Hg. This can be explained by the fact that the chances of oxygen tension reaching very low values are remote in the habitat as revealed by the hydrographical

## TABLE 16

Figs. 70–78. Tend of variations in the rate of oxygen uptake of *C. fluviatilis* of standard weights 10, 20 and 30 mg in declining $pO_2$ in various salinities.

Fig.70. 1‰ S; Fig.71. 1‰ S to 17‰ S; Fig.72. 1‰ S to 33‰ S; Fig.73. 17 ‰ S; Fig.74. 17‰ S to 33‰ S; Fig.75. 17‰ S to 1‰ S; Fig.76. 33‰ S; Fig. 77. 33‰ S to 17‰ S and Fig.78. 33‰ S to 1‰ S.

PLATE 16

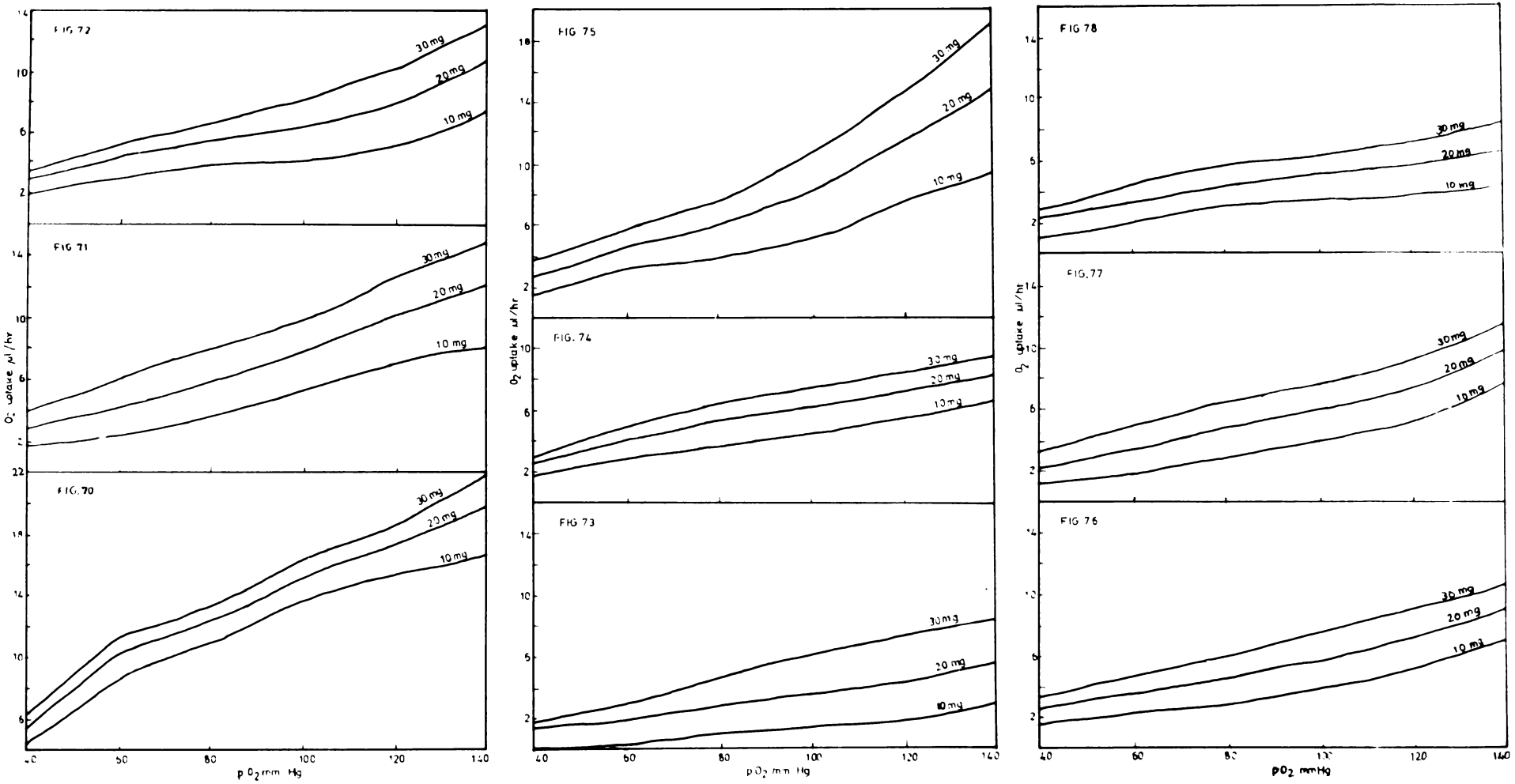
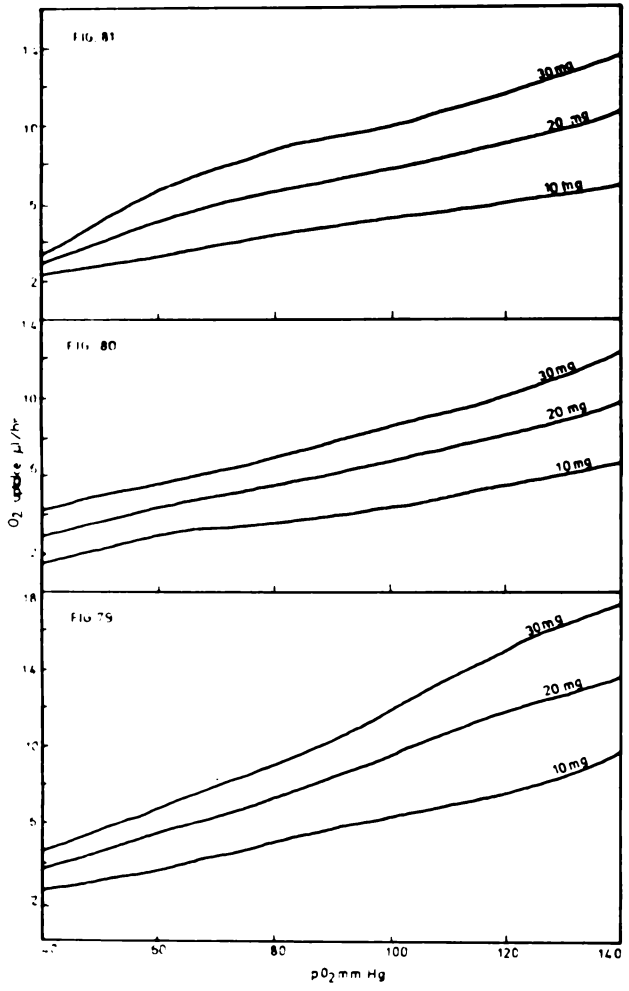


FIG 72
30 mg
20 mg
10 mg
FIG 71
30 mg
20 mg
10 mg
FIG. 70
30 mg
20 mg
10 mg
O2 uptake µl/hr
p O2 mm Hg
FIG 75
30 mg
20 mg
10 mg
FIG. 74
30 mg
20 mg
10 mg
FIG 73
30 mg
20 mg
10 mg
O2 uptake µl/hr
p O2 mm Hg
FIG 78
30 mg
20 mg
10 mg
FIG. 77
30 mg
20 mg
10 mg
FIG 76
30 mg
20 mg
10 mg
O2 uptake µl/hr
pO2 mm Hg

## PLATE 17

Figs. 79–87. Trend of variations in the rate of oxygen uptake of *C. willeyi* of standard weights 10, 20 and 30 mg in declining $pO_2$ in various salinities.

Fig. 79. 1‰ S; Fig.80 1‰ S to 17‰ S;
Fig. 81. 1‰ S to 33‰ S; Fig. 82. 17‰ S;
Fig. 83. 17‰ S to 33‰ S; Fig.84. 17‰ S to 1‰ S;
Fig. 85.33‰ S; Fig. 86. 33‰ S to 17‰ S, and
Fig. 87. 33‰ S to 1‰ S.


30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg

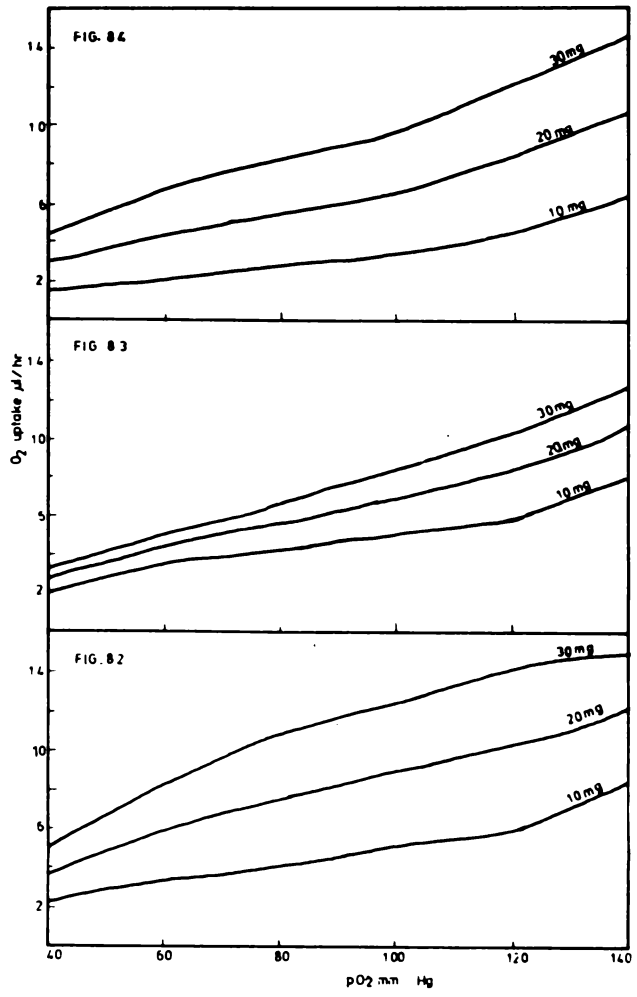


FIG. 84
30 mg
20 mg
10 mg
FIG. 83
30mg
20mg
10mg
FIG. 82
30 mg
20mg
10mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg

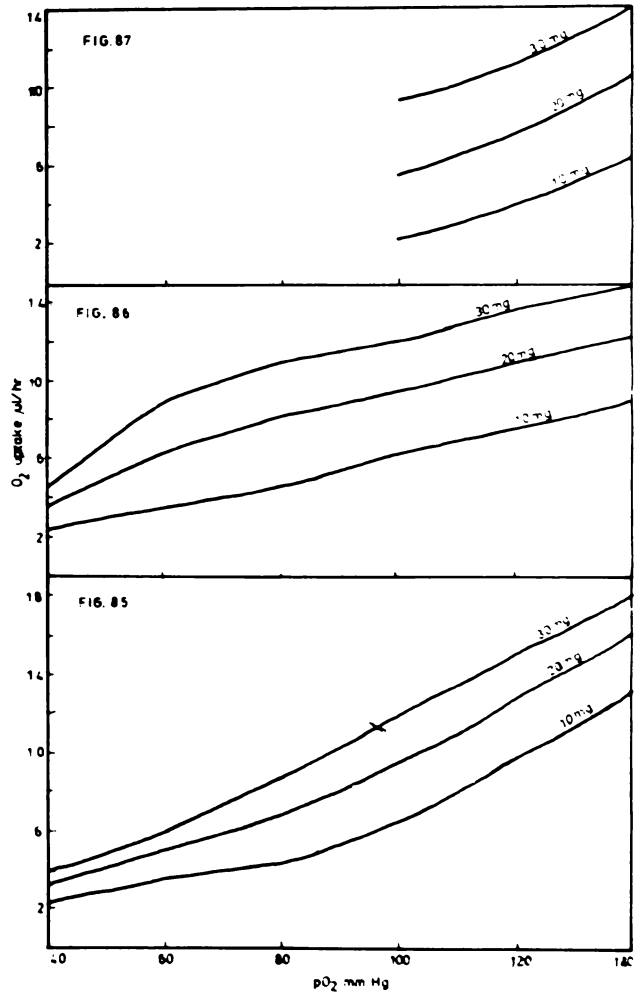


FIG. 87
FIG. 86
30 mg
20 mg
FIG. 85
30 mg
20 mg
10 mg
$O_2$ uptake µl/hr
$pO_2$ mm Hg

studies. This is particularly true since the attack of Sphaeroma is concentrated mainly to the upper layers of water where oxygen supply is comparatively high as pointed out by Cheriyan (1973). Moreover, the animals can escape from the burrows in the wood in extremely adverse conditions. Cirolana spp. are swift swimmers and hence they can avoid areas of low oxygen concetnration if at all needed.

## REFERENCES


Amberson, W.R., Mayerson, H.S. and Scott, W.J. 1924 The influence of oxygen tension upon metabolic rate in invertebrates. J. gen. Physiol., 7, 171-176.

Barnard, J.L. 1955 The wood boring habits of Chelura terebrans Philippi in Los Angeles Harbour. Essays in Natural History in honour of Captain Allan Hancock on the occasion of his Birthday. Univ. Southern California Press, 87-96.

Barnard, K.H. 1920 Contributions to the crustacean fauna of South Africa. VI. Further additions to the list of marine Isopoda. Ann. S. Afr. Mus., 17, 319-438.

Barnard, K.H. 1935 Report on some Amphipoda, Isopoda, and Tanaidacea in the collections of the Indian Museum. Rec. Indian Mus., 37, 279 - 319.

Barnard, K.H. 1936 Isopods collected by the 'Investigator'. Rec. Indian Mus., 38, 147 - 191.

Barnard, K.H. 1940 Contributions to the crustacean fauna of South Africa. XII. Further additions to the Tanaidacea, Isopoda and Amphipoda together with keys for the identification of hitherto recorded marine and fresh-water species. Ann. S. Afr. Mus. 32, 381 - 543.

Barnes, H. and Barnes, M. 1959 Studies on the metabolism of cirripedes. The relation between body weight, oxygen uptake and species habitat. Veröff. Inst. Meeresforsch. Bremerhaven., 6, 515-523.

| | | |
|---|---|---|
| Barnes, H. and Barnes, M. | 1969 | Seasonal changes in the acutely determined oxygen consumption and effect of temperature for three common cirripedes, Balanus balanoides (L.), B. balanus (L.) and Chthamalus stellatus (Poli.). J. exp. mar. Biol. Ecol. 4, 36–50. |
| Bassindale, R. | 1943 | A comparison of the varying salinity conditions of the Tees and Severn estuaries. J. Anim. Ecol., 12, 1–10. |
| Bate, C.S. | 1866 | Carcinological gleanings No.3. Ann. Mag. Nat. Hist., 17, 28. |
| Beadle, L.C. | 1957 | Comparative physiology: Osmotic and ionic regulation in aquatic animals. A. Rev Physiol., 19, 329–354. |
| Beadle, L.C. | 1961 | Adaptations of some aquatic animals to low oxygen levels and to anaerobic conditions. Symp. Soc. exp. Biol., 15, 121 – 131. |
| Becker, G. | 1958 | Report to the Government of India on the Protection of Wood against Marine Borers. F.A.O. Report No. 795. |
| Beeson, C.F.C. | 1936 | Martesia, a marine borer. Indian Forester, 62, 286 – 289. |
| Bertalanffy, L.von | 1957 | Quantitative laws in the metabolism and growth. Quart. Rev. Biol., 32, 217–231. |
| Black, V.S. | 1957 | Excretion and Osmoregulation. In The Physiology of Fishes Vol.1. Ed. M.E. Brown., Academic Press, New York, 163–205. |

Blackman, F.F. 1905 Optima and limiting factors. Ann. Bot., 19, 281 - 295.

Brand, T.F. von 1945 The anaerobic metabolism of invertebrates. Biodynamica, 5, 165-295.

Brody, S. 1945 Bioenergetics and Growth. Hafner, New York.

Brody, S. and Procter, R.C. 1932 Relation between basal metabolism and mature body weight in different species of mammals and birds. Missouri Agr. Exp. Sta. Res. Bull., 166, 89 - 101.

Bull, H.O. 1931 Resistance of Eurytemora hirundoides, a brackish water copepod, to oxygen depletion. Nature, 127, 406-407.

Bullock, T.H. 1955 Compensation for temperature in the metabolism and activity of poikilotherms. Biol. Rev. 30, 311-342.

Bulnheim, H. -P. 1974 Respiratory metabolism of Idotea balthica (Crustacea, Isopoda) in relation to environmental variables, acclimation processes and moulting. Helgolander wiss. Meeresunters, 26, 464 - 480.

Lanchester, W.F. 1902 On the Crustacea collected during the Skeat Expedition to the Malaya Peninsula. Proc. zool. Soc. London, 363 - 379.

Calman, W.T. 1921 Notes on marine wood-boring animals. II. Crustacea. Proc. zool. Soc., London, 215 - 220.

| | | |
|---|---|---|
| Calman, W.T. | 1936 | Marine boring animals injurious to submerged structures (Revised by G.I. Crawford). Brit. Mus. nat. Hist. Economic Series, 10., 1-38. |
| Cheriyan, P.V. | 1963 | Studies on the salinity and temperature variations in the Port of Cochin. J. Timb. Dry. Preserv. Ass. India, 9, 7-21. |
| Cheriyan, P.V. | 1967 | A simple device for filtering and aerating water used in breeding experiments. J. Timb. Dev. Ass. India, 13., 1-2. |
| Cheriyan, P.V. | 1967a | Hydrographical studies in and around the Cochin Harbour. Bull. Dep. Mar. Biol. Oceanogr. Univ. Kerala., 3, 9-17. |
| Cheriyan, P.V. | 1973 | Studies on Sphaeroma terebrans Bate (Crustacea, Isopoda) of the Port of Cochin. forma et functio, 6, 1-68. |
| Cheriyan, P.V. and Cherian, C.J. | 1968 | A preliminary report on the salinity tolerance of Sphaeroma terebrans Bate. J. Timb. Dev. Ass. India., 14, 1-5. |
| Chilton, C. | 1924 | Fauna of the Chilka Lake. Tanaidacea and Isopoda. Mem. Indian Mus., 5, 875-895. |
| Chilton, C. | 1926 | Zoological results of a tour in the Far East. The Tanaidacea and Isopoda of Tale Sap. Rec. Indian Mus., 28, 173-185. |
| Clapp, W.F. and Kenk, R. | 1963 | Marine Borers - An Annotated Bibliography. Office of Naval Research, Dept. of the Navy, Washington, D.C. |

| | | |
|---|---|---|
| Coull, B.C. and Vernberg, W.B. | 1970 | Harpacticoid copepod respiration: Enhydrosoma propinquum and Longipedia helgolandica. Mar. Biol., 5, 341-344. |
| Dehnel, P.A. | 1960 | Effect of temperature and salinity on the oxygen consumption of two intertidal crabs. Biol. Bull., 118, 215-249. |
| Duncan, A. and Klekowski, K.Z. | 1967 | The influence of salinity on the survival, respiratory rate and heart beat of young Potamopyrgus jenkinsi (Smith), Prosobanchiata. Comp. Biochem. Physiol., 22, 495 - 505. |
| Edney, E.B. and Spencer, J.O. | 1955 | Cutaneous respiration in woodlice. J. exp. Biol., 32, 256-269. |
| Edwards, G.A. | 1946 | The influence of temperature upon the oxygen consumption of several arthropods. J. cell. comp. Physiol., 27, 53-64. |
| Eliassen, E. | 1953 | The energy metabolism of Artemia salina in relation to body size, seasonal rythms and different salinities. Arbok Univ. Bergen (Naturvitensk R.), 11, 1-17. |
| Ellenby, C. | 1951 | Body size in relation to oxygen consumption and pleopod beat in Ligia Oceanica L. J. exp. Biol., 28, 492-507. |
| Eltringham, S.K. | 1965 | The respiration of Limnoria (Isopoda) in relation to salinity. J. mar. biol. Ass. U.K., 45, 145-152. |
| Erlanson, E.W. | 1936 | A preliminary survey of marine boring organisms in Cochin Harbour. Curr. Sci., 4, 726-732. |

Fish, J.D., and Preece, G.S. 1970 The ecophysiological complex of Bathyporeia pilosa and B. pelagica (Crustacea: Amphipoda)-1. Respiration rates. Mar. Biol., 5, 22-28.

Fox, H.M. and Simmonds, B.G. 1933 Metabolic rates of aquatic arthropods from different salinities. J. exp. Biol., 10, 67-78.

Frankenberg, D. and Burbanck, W.D. 1963 A comparison of the physiology and ecology of the estuarine isopod Cyathura polita in Massachusetts and Georgia. Biol. Bull., 125, 81-95.

Fry, F.E.J. 1947 Effects of the environments on animal activity. Univ. Toronto Stud. Biol., 55 (Publ. Ontario Fish. Res. Labs.) 68,1-62.

Ganapati, P.N. and Prasada Rao, D.G.V. 1960 Studies on the respiration of barnacles: Oxygen uptake and metabolic rate in relation to body size in Balanus amphitrite communis (Darwin). J. Anim. Morph. Physiol., 7, 27-31.

Ganapati, P.N. and Prasada Rao, D.G.V. 1962 Studies on the respiration of barnacles: The temperature characteristics of the respiratory movements in Balanus amphitrite communis (Darwin). J. Anim. Morph. Physiol., 9, 72-78.

George, R.Y. 1967 Observations on the osmotic behaviour of Sphaeroma walkeri, a stenohaline isopod. Proc. Symp. Crustacea, Cochin., Mar. biol. Ass. India Pt.3, 1067-1073.

Gross, W.J. 1957 An analysis of response to osmotic stress in selected decapod Crustacea. Biol. Bull., 112, 43-62.

Gunter, G. 1956 Some relations of faunal distributions to salinity in estuarine waters. Ecology, 37, 616-619.

Hagerman, L. 1969 Respiration, anaerobic survival and diel locomotory periodicity in Hirschmannia viridis Muller (Ostracoda). Oikos, 20, 384-391.

Hagerman, L. 1970 The oxygen consumption of Crangon vulgaris (Fabricius), (Crustacea, Natantia) in relation to salinity. Ophelia, 7, 283-292.

Haq, S.M. 1967 Nutritional physiology of Metrida lucens and M. longa from the Gulf of Maine. Limnol. Oceanogr., 12, 40-51.

Hemmingsen, A.M. 1950 The relation of standard (basal) energy metabolism to total fresh weight of living organisms. Rep. Steno mml. Hosp. Copenh., 4, 7-58.

Hemmingsen, A.M. 1960 Energy metabolism as related to body size and respiratory surfaces and its evolution. Rep. Steno mml. Hosp. Copenh. 9, 1-110.

Henze, M. 1910 Ueber den einfluss des sauerstoff-drucks auf den gaswechsel einiger meerestieren. Biochem. Z., 26, 255-278.

Hiestand, W.A. 1931 The influence of varying tensions of oxygen upon the respiratory metabolism of certain aquatic insects and the cray fish. Physiol. Zool., 4, 246-270.

Job, S.V. 1957 The routine oxygen consumption of the milk fish. Proc. Indian Acad. Sci., 45, 302-313.

John, P.A. 1955 Studies on Melita zeylanica, an amphipod destructive to submerged timber. Bull. Centr. Res. Inst. Trivandrum, 4C, 117-126.

John, P.A. 1968 Habits, Structure and Development of Sphaeroma terebrans. (A wood-boring Isopod). University of Kerala Publications, Trivandrum.

Jones, E.B.G. and Eltringham, S.K. 1971 Marine Borers, Fungi and Fouling Organisms of Wood. Paris: O.E.C.D.

Jones, M.B. 1974 Survival and oxygen consumption in various salinities of three species of Idotea (Crustacea, Isopoda) from different habitats. Comp. Biochem. Physiol., 48A, 501-506.

Kinne, O 1964 The effects of temperature and salinity on marine and brackish water animals. II. Salinity and temperature - salinity combinations. Oceanogr. mar. Biol. A. Rev., 2, 281-339.

Kinne, O 1966 Physiological aspects of animal life in estuaries with special reference to salinity. Neth. J. Sea Res., 3, 222-244.

Kinne, O. 1971 Salinity: Animals- Invertebrates. In Marine Ecology Vol.1, Pt.2 Ed. O. Kinne., Wiley-Interscience, London, 821-995.

Kleiber, M. 1932 Body size and metabolism. Hilgardia, 6, 315-353.

Kleiber, M. 1947 Body size and metabolic rate. Physiol. Rev. 27, 511-541

Knudsen, M. 1901 Hydrographische Tabellen. Bianco Luno, Copenhagen.

Krogh, A. 1941 The Comparative Physiology of Respiratory Mechanisms. University of Pennsylvania Press, Philadelphia.

Kutty, M.N. 1969 Oxygen consumption of the prawns Penaeus indicus H. Milne-Edwards and Penaeus semisulcatus DeHaan. FAO Fish. Rep., 57, 957-969.

Lance, J. 1963 The salinity tolerance of some estuarine planktonic copepods. Limnol. Oceanogr.,8, 440-449.

Lance, J. 1965 Respiration and osmotic behaviour of the copepod Acartia tonsa in diluted sea water. Comp. Biochem. Physiol., 14, 155 - 165.

Ledebuhr, J.F. Von 1939 Der sauerstoff als okologischer faktor. Ergebn. Biol., 16, 173-261.

Leffler, C.W. 1972 Some effects of temperature on the growth and metabolic rate of juvenile blue crab, Callinectes sapidus in the laboratory. Mar. Biol., 14, 104-110.

Leffler, C.W. 1973 Metabolic rate in relation to body size and environmental oxygen concentration in two species of xanthid crabs. Comp. Biochem. Physiol., 44A, 1047-1052.

Lockwood, A.P.M. 1967 Aspects of the Physiology of Crustacea. W.H. Freeman and Company, San Francisco.

Lofts, B, 1956 The effects of salinity changes on the respiratory rate of the prawn, Palaemonete varians (Leach). J. exp.Biol., 33, 730-736.

McFarland, W.N. and Pickens, P.E. 1965 The effects of season, temperature and salinity on standard and active oxygen consumption of the grass shrimp Palaemonetes vulgaris (Say). Canad. J. Zool., 43., 571-585.

MacGinitie, G.E. and MacGinitie, N. 1949 Natural History of Marine Animals. McGraw-Hill Book Co., New York.

McLeese, D.W. 1964 Oxygen consumption of the lobster Homarus americanus, Milne-Edwards. Helgol. wiss. Meeresuntersuch, 10, 7-18.

Moore, H.B. 1958 Marine Ecology. Wiley, New York.

Moshiri, G.A., Cummins, K.W. and Costa, R.R. 1969 Respiratory energy expenditure by the predaceous zooplankter Leptodora kindtii (Focke) (Crustacea: Cladocera). Limnol. Oceanogr., 14, 475-484.

Maloeuf, N.S.R. 1937 Studies on the respiration and osmo-regulation of animals. I. Aquatic animals without an oxygen transporter in their internal medium. Z. vergl. Physiol., 25, 1-28.

Maloeuf, N.S.R. 1937a Studies on the respiration and osmo-regulation of animals. II. Aquatic animals with an oxygen transporter in their internal medium. Z. vergl. Physiol., 25, 29-42.

Menzies, R.J. 1957 The marine borer family Limnoriidae (Crustacea, Isopoda). Bull. Mar. Sci. Gulf and Caribbean, 7, 101-200.

Muller, I. 1943 Untersuchungen über die Gesetzlichkeit des Wachstums.X.Weiteres zur Frage der Abhängigkeit der Atmung von der Körpergrosse. Biol. Zentr., 63, 446-453.

| | | |
|---|---|---|
| Nagabhushanam, R. and Gopalakrishnamurthy, K. | 1965 | Tolerance of Cirolana fluviatilis to waters of low salinity (Arthropoda: Crustacea). Sci. Cult., 31, 437-438. |
| Nagabhushanam, R. and Gopalakrishnamurthy, K. | 1965a | Oxygen consumption of Cirolana fluviatilis in different salinities (Arthropoda: Crustacea). J. Anim. Morphol. Physiol., 12, 264-265. |
| Nair, N.B. and Saraswathy, M. | 1971 | The biology of wood-boring teredinid molluscs. Adv. mar. Biol., 9, 335-509. |
| Newell, R.C. | 1970 | Biology of Intertidal Animals. Logos Press Limited, London. |
| Newell, R.C. and Northcroft, H.R. | 1965 | The relationship between cirral activity and oxygen uptake in Balanus balanoides. J. mar. biol. Ass. U.K., 45, 387-403. |
| Newell, R.C. and Pye, V.I. | 1971 | Variations in the relationship between oxygen consumption, body size and summated tissue metabolism in the winkle Littorina littorea. J. Mar. Biol. Ass. U.K., 51, 315-338. |
| Newell, R.C., Wieser, W. and Pye, V.I. | 1974 | Factors affecting oxygen consumption in the woodlouse Porcellio scaber Latr. Oecologia, 16, 31-51. |
| Nicol., J.A.C. | 1960 | The Biology of Marine Animals. Wiley, New York. |
| Omer-Cooper, J. and Rawson, J.H. | 1934 | Notes on the British Sphaeromatidae (Crustacea: Isopoda). Rep. Dove mar. Lab. Ser., 3,2, 22-58. |

| | | |
|---|---|---|
| Pearse, A.S., and Gunter, G. | 1957 | Salinity. In Treatise on Marine Ecology and Paleoecology, Vol.1, Ed. J.W. Hedgpeth. Mem. Geol. Soc. Am., 67, 129-157. |
| Phillipson, J. and Watson, J. | 1965 | Respiratory metabolism of the terrestrial isopod Oniscus asellus L. Oikos, 16, 78-87. |
| Pillai, N.K. | 1961 | Wood-boring Crustacea of India. Government of India Press, Simla. |
| Pillai, N.K. | 1967 | The role of Crustacea in the destruction of submerged timber. Proc. Symp. Crustacea, Cochin., Mar. biol. Ass. India Pt. 4, 1274-1283. |
| Potts, W.T.W. and Parry, G. | 1964 | Osmotic and Ionic Regulation in Animals. Pergamon Press, New York. |
| Prasada Rao, D.G.V. and Ganapati, P.N. | 1968 | Respiration as a function of oxygen concentration in intertidal barnacles. Mar. Biol., 1, 309-310. |
| Prasada Rao, D.G.V. and Ganapati, P.N. | 1969 | Oxygen consumption in relation to body size in the barnacle, Balanus tintinnabulam tintinnabulam (L.). Comp. Biochem. Physiol., 28, 193-198. |
| Pritchard, A.W. and Kasparek, R.A. | 1966 | The relationship of oxygen tension and metabolism in two mud dwelling shrimps, Callianassa californiensis and Upogebia pugettensis. Am. Zool., 6, 506. |
| Prosser, C.L. | 1955 | Physiological variation in animals. Biol. Rev., 30, 229-262. |
| Prosser, C.L. | 1958 | The nature of physiological adaptation. In Physiological Adaptation Ed. C.L. Prosser. Amer. Physiol. Soc., Washington, D.C., 167-180. |

| | | |
|---|---|---|
| Prosser, C.L. and Brown, F.A. | 1961 | Comparative Animal Physiology 2nd Ed. Saunders, Philadelphia. |
| Purushotham, A and Rao, K.S. | 1971 | The First Progress Report of the Committee for the Protection of Timber Against Marine Organisms Attack in the Indian Coastal Waters for the Period 1953-'70. J. Timb. Dev. Ass. India, 17, 1-74. |
| Purushotham, A. and Rao, K.S. | 1971a | The First Progress Report of the Committee for the Protection of Timber Against Marine Organisms Attack in the Indian Coastal Waters for the Period 1953-'70. J. Timb. Dev. Ass. India, 17, 75-139. |
| Rao, K.P. | 1958 | Oxygen consumption as a function of size and salinity in Metapenaeus monoceros Fab. from marine and brackish water environments. J. exp. Biol., 35, 307-313. |
| Rao, K.P. and Bullock, T.H. | 1954 | $Q_{10}$ as a function of size and habitat temperature in poikilotherms. Amer. Nat., 87, (838), 33-43. |
| Ray, D.L. | 1959 | Marine Boring and Fouling Organisms (Ed). Univ. Washington Press, Seattle. |
| Ray, D.L. and Julian, J.R. | 1952 | Occurrence of cellulase in Limnoria. Nature, 169, 32. |
| Reinders, D.E. | 1933 | Die funktion der corpora alba bei Porcellio scaber. Z. vergl. Physiol., 20, 273-291. |
| Remane, A. | 1958 | Okologie des Brackwassers. In Die Biologie des Brackwassers, Stuttgart: Schweizerbartsche Verlag, 1-213. |

| | | |
|---|---|---|
| Remane, A. and Schlieper, C. | 1958 | Die Biologie des Brackwassers, Schweizerbart, Stuttgart. (Binnengewasser, 22). |
| Ricketts, E.F. and Calvin, J. | 1962 | Between Pacific Tides. Stanford University Press, California. |
| Roberts, J.L. | 1957 | Thermal acclimation of metabolism in the crab Pachygrapsus crassipes Randall.I. The influence of body size, starvation and moulting. Physiol. Zool., 30, 232-242. |
| Robertson, J.D. | 1957 | Osmotic regulation in aquatic invertebrates. In, Recent Advances in Invertebrate Physiology. Ed. B.T. Scheer. University of Oregon Press, Oregon, 229-246. |
| Robertson, J.D. | 1960 | Osmotic and ionic regulation. In The Physiology of Crustacea, Vol. I. Ed. T.H. Waterman, Academic Press, New York, 317-340. |
| Sankaranarayanan, V.N. and Qasim, S.Z. | 1969 | Nutrients of Cochin Backwater in relation to environmental characteristics. Mar. Biol., 2, 236-247. |
| Schachter, D. | 1964 | Etude comparative due métabolisme respiratoire de Sphaeroma hookeri Leach (Crustacé isopode) de la Durancole et des etangs mediterraneens. C.R. Acad. Sci. Paris, 259, 2917-2919. |
| Schawbe, E. | 1933 | Uber die Osmoregulation verschiedener Krebse (Malacostracen). Z. vergl. Physiol. 19, 183-236. |
| Sellius, G. | 1733 | Historia naturalis Teredinis seu Xylophagi marini tubuloconchoidis Speciatim Belgici. Trajecti ad Rhenum. |

| | | |
|---|---|---|
| Small, L.F. and Hebard, J.F. | 1967 | Respiration of vertically migrating maritime crustacean Euphausia pacifica Hansen. Limnol. Oceanogr., 12, 272-280. |
| Stebbing, T.R.R. | 1902 | South African Crustacea. II. Mar. Invest. S. Afr., 1-92. |
| Stebbing, T.R.R. | 1904 | Gregarious Crustacea of Ceylon. Spolia Zeylanica, 2, 1-29. |
| Stebbing, T.R.R. | 1911 | Indian isopods. Rec. Indian Mus., 6, 179-191. |
| Subrahmanyam, C.B. | 1957 | Relationship between the body weight and the oxygen consumption in Emerita asiatica (M.Edw.) Curr. Sci., 26, 155-156. |
| Subrahmanyam, C.B. | 1962 | Oxygen consumption in relation to body weight and oxygen tension in the prawn Penaeus indicus Milne Edwards. Proc. Indian Acad. Sci., 55, 152-161. |
| Tang, P.S. | 1933 | On the rate of oxygen consumption of tissues and lower organisms as a function of oxygen tension. Quart. Rev. Biol., 8, 260-270. |
| Teal, J.M. | 1959 | Respiration of crabs in Georgia salt marshes and its relation to their ecology. Physiol. Zool., 32, 1-14. |
| Thomas, H.J. | 1954 | The oxygen uptake of the lobster (Homarus vulgaris Edw.) J. exp. Biol., 31, 228-251. |
| Thompson, R.K. and Pritchard, A.W. | 1969 | Respiratory adaptations of two burrowing crustaceans, Callianassa californiensis and Upogebia pugettensis (Decapoda, Thalassinidae), Biol. Bull., 136, 274-287. |

| | | |
|---|---|---|
| Turner, R.D. | 1966 | A Survey and Illustrated Catalogue of the Teredinidae. The Museum of Comparative Zoology, Harward University, Mass. |
| Van Weel, P.B. Randall, J.E. and Takata, M. | 1954 | Observations on the oxygen consumption of certain marine Crustacea. Pacif. Sci., 8, 209-218 |
| Vernberg, F.J. | 1972 | Dissolved gases: Animals. In Marine Ecology. 1. Pt.3, Ed.O.Kinne. Wiley-Interscience, London, 1491-1526. |
| Vernberg, F.J. and Costlow Jr, J.D. | 1966 | Studies on the physiological variation between tropical and temperate zone fiddler crabs of the genus Uca. IV. Oxygen consumption of larvae and young crabs reared in the laboratory. Physiol. Zool. 39, 36-52. |
| Vernberg, W.B. and Vernberg, F.J. | 1972 | Environmental Physiology of Marine Animals. Springer-Verlag, New York. |
| Visscher, J.P. | 1928 | Nature and extent of fouling of ships' bottom. Bull. Bur. Fish., 43 pt.2, 193-252. |
| Waldichuk, M. and Bousfield, E.L. | 1962 | Amphipods in low oxygen marine waters adjacent to a sulphite pulp mill. J. Fish Res. Bd. Canada, 19, 1163-1165. |
| Welsh, J.H. and Smith, R.I. | 1953 | Laboratory Exercises in Invertebrate Physiology. Burges Publishing Co. Minneapolis. |
| Weymouth, F.W., Crisman, J.M., Hall, V.E., Belding, H.S. and Field, J. | 1944 | II. Total and tissue respiration in relation to body weight. A comparison of the kelp crab with other crustaceans and with mammals. Physiol. Zool., 17, 50-71. |

| | | |
|---|---|---|
| Wiens, A.W. and Armitage, K.B. | 1961 | The oxygen consumption of the crayfish Orconectes immunis and Orconectes nais in response to temperature and to oxygen saturation. Physiol. Zool., 34, 39-54. |
| Wieser, W. | 1962 | Adaptations of two intertidal isopods. I. Respiration and feeding in Naesa bidentata (Adams) (Sphaeromatidae). J. mar. biol. Ass. U.K., 42, 665-682. |
| Wolvekamp, H.P. and Waterman, T.H. | 1960 | Respiration. In The Physiology of Crustacea, 1. Ed. T.H. Waterman. Academic Press, New York and London. |
| Woods Hole Oceanographic Institution | 1952 | Marine Fouling and its Prevention. U.S. Naval Institute, Maryland. |
| Yonge, C.M. | 1927 | The absence of cellulase in Limnoria. Nature, 119, 855. |
| Zeuthen, E. | 1947 | Body size and metabolic rate in the animal kingdom. C.R.Lab. Carls b. Ser. chim., 26, 15-161. |
| Zeuthen, E. | 1953 | Oxygen uptake as related to body size in organisms. Quart. Rev. Biol., 28, 1-12. |
| Zeuthen, E. | 1955 | Comparative physiology: Respiration: A. Rev. Physiol., 17, 459-482. |



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Deterioration of timber in sea water is mainly caused by animals which bore into wood, either for shelter or for food. They belong to two groups, Mollusca and Crustacea. The molluscan wood-borers belong to two bivalve families viz. Teredinidae and Pholadidae and are commonly called 'shipworms' and 'piddocks' respectively. The shipworms are highly specialised bivalves remarkably adapted for boring into wood, with a soft and delicate worm like body, provided with a shell having denticulated ridges for rasping wood. The pholadids bore into a variety of substrata and the wood-borers are mainly Martesia and Xylophaga. It is believed that the shipworms partly obtain their nourishment from wood while the pholadids bore into wood for shelter (Purushotham and Rao 1971). The crustacean wood borers belong to three families, Cheluridae of order Amphipoda and Limnoriidae and Sphaeromidae of order Isopoda. Besides these Melita zeylanica, a gammarid amphipod has been reported to be causing damage to wood by browsing action (John 1955). The limnoriids and sphaeromids are the more destructive crustacean borers and are commonly called as the 'gribbles' and the 'pill bugs' respectively. Unlike the molluscan borers the crustaceans can leave their tunnels at random, swim about and select new places for attack. However, whether these crustaceans eat and digest wood has been a problem of dispute. Barnard (1955) observed that chelurids might be browsing on microscopic organisms which grow on the wood, consequently ingesting some woody matter also during the process. John (1955) showed that Melita zeylanica can digest callulose. Yonge (1927) could not find cellulase in Limnoria and concluded that it feeds on the microscopic