STUDIES ON THE QUEENSLAND LUNGFISH, *NEOCERATODUS FORSTERI* (KREFFT)

II. THERMAL ACCLIMATION

By G. C. Grigg*

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Summary

Six juvenile *Neoceratodus* of convenient size for respirometry (27–51 g) were available for study. Fish of this size are very rarely taken and the opportunity was used to examine the ability of *Neoceratodus* to undergo metabolic acclimation. Metabolic rate–temperature curves were constructed for fish with cold (18°C) and warm (25°C) thermal histories, using oxygen consumption as a measure of the rate of metabolism. The Q_{10} of fish with warm history ($Q_{10} = 2 \cdot 42$) was higher than that for fish with cold history($Q_{10} = 1 \cdot 55$), and it was seen that there was partial thermal acclimation over the range investigated.

I. Introduction

The evolutionary position of the Dipnoi makes any aspect of their physiology one of interest. The present study of metabolic response to temperature in *Neoceratodus* was carried out with a view to comparing it with that known for teleosts, and to examine the ecological significance of any ability to undergo metabolic adjustment, if such were found.

Research on compensation for temperature in the metabolism and activity of poikilotherms has been excellently reviewed by Bullock (1955). Similar work on teleost fish has been reviewed by Fry (1957). The thermal history of an animal may change not only the position, but also the shape and form of the rate–temperature curve (Wells 1935; Rao and Bullock 1954). Part of two such curves were examined in *Neoceratodus*, using fish with a different thermal history in each case. Differences between the curves were assumed to be the result of metabolic adjustment to temperature during the period of acclimation (used in the sense of Prosser and Brown 1961).

II. Material and Methods

Until the end of the last century the distribution of *Neoceratodus* had been confined to the Mary and Burnett river systems. However, in 1896 fish were released in several other southern Queensland rivers, including the Brisbane River (O'Connor 1897), in which there is now a thriving and widespread population. The fish used in this series of experiments were taken from the Brisbane River at Mt. Crosby.

The adult fish are quite large, commonly 3 ft long, and respirometry studies on fish so large were impracticable. However, the author was fortunate in obtaining six healthy juveniles ranging in weight from 27 to 51 g. Juvenile fish are taken only very

* Department of Zoology, University of Queensland, Brisbane.

rarely (Illidge 1894; Bancroft 1912, 1928), and even though *Neoceratodus* was discovered in 1870, no juveniles were recorded prior to those described by Longman (1929), although some had been reared artificially from eggs before this time. Although the restricted number was a limitation upon the extensiveness of the study, it was fortuitious that even six fish of convenient size for respirometry were available.

The rate of oxygen consumption was used as a measure of metabolism, and was determined using a modified Barcroft respirometer of the type described by Morris (1963). The 1-l. respirometer vessel was ideal for the size of the fish, and the water-bath in which the whole respirometer was immersed was held at the required temperature within ±0·1 degC.

TABLE 1

STANDARD OXYGEN CONSUMPTION OF NEOCERATODUS ACCLIMATED AT 18°C

Weight of Fish (g)	Number of Readings	Mean (ml g^{-1} hr^{-1})	S.D. (ml g^{-1} hr^{-1})	Coefficient of Variation (%)
		Standard at 18°C		
27	3	0·021	0·0000	0
33	5	0·020	0·0022	11
28	4	0·019	0·0000	0
44	5	0·019	0·0008	4
29	3	0·029	0·0000	0
50	4	0·023	0·0011	5
		Standard at 25°C		
27	3	0·033	0·0029	9
33	5	0·031	0·0040	13
28	4	0·023	0·0015	7
44	3	0·031	0·0030	10
29	3	0·035	0·0000	0
50	4	0·029	0·0013	4

Various precautions necessary when using respirometry as a measure of metabolism, as discussed by Fry (1957), were taken during the present study. Winkler determinations on water in the respirometer before and after several "runs" showed that the oxygen level had not fallen to what could approach a critical tension, being only slightly depressed. The limited size of the vessel caused no alarm to the fish, which are normally thigmotactic. Wells (1932) described an initially high oxygen consumption in fish following transfer to a respirometer, the result of disturbance due to handling. This was not observed in *Neoceratodus*, presumably because of their normally passive reaction to being handled, and thus, once the respirometer was equilibrated, readings could be immediately taken. On no occasion did the fish surface to take air during experiments (they do not do so when inactive—to be discussed in Part III of this series). Throughout the acclimation periods, and during respirometry, the fish were exposed to a normal photoperiod. All experiments were carried out in winter and measurements made at about the same time of day, so that any errors due to endogenous metabolic rhythms were minimized. The fish, being juvenile, were sexually inactive, and at least 4 days were allowed to elapse after feeding before a fish was run in the respirometer.

The six fish had a cold history when acquired, and were held in the laboratory at approximately 18°C for about a month. Their oxygen consumption was then measured at both 18°C and 25°C. These same fish were then maintained at 25°C for more than 1 month to allow acclimation. During this period, two of the fish died after jumping from the tank. The remaining four fish were run in the respirometer at 25°C, and then at 18°C.

Table 2

STANDARD OXYGEN CONSUMPTION OF NEOCERATODUS ACCLIMATED AT 25°C

Weight of Fish (g)	Number of Readings	Mean (ml g^{-1} hr^{-1})	S.D. (ml g^{-1} hr^{-1})	Coefficient of Variation (%)
		Standard at 25°C		
27	4	0·030	0·0029	10
33	5	0·026	0·0024	9
44	6	0·025	0·0033	13
29	5	0·022	0·0043	19
		Standard at 18°C		
27	5	0·016	0·0021	13
33	4	0·014	0·0031	21
44	4	0·014	0·0022	16
29	3	0·010	0·0000	0

III. Results

Three levels of oxygen consumption have been defined for fish, in relation to activity (Fry 1957). These are standard (nearest possible approximation to basal metabolism), routine (oxygen consumption of a fish whose only movements are spontaneous), and active (when a fish is stimulated to maximum activity). No spontaneous movement occurred in the specimens during respirometry, and thus they behaved ideally for determinations that may be justifiably regarded as standard oxygen consumption. (This was as expected, since the species is typically inactive during the day and active at night, which will be discussed in Part III of this series).

Tables 1 and 2 summarize the data obtained in each series of observations and indicate the extent of variability in the values obtained for individual fish. The highest coefficient of variability for a series of determinations on the same fish was 21%. Figure 1 is based on the pooled data for each of four series of measurements which are summarized in Table 3. By t test the difference between the means of the cold and warm acclimated fish is highly significant at 18°C ($t = 3 \cdot 8$, $P = 0 \cdot 01$) but at 25°C there is no significant difference ($t = 1 \cdot 7$, $P = 0 \cdot 1$). The values of Q_{10} for both cold acclimated (1·55) and warm acclimated (2·42) fish are indicated on Figure 1.

IV. Discussion

Bullock (1955) reviews several aspects of thermal acclimation of poikilotherms. He points out that, as a rule, warm acclimated animals have a lower metabolic rate, and a higher Q_{10} than do cold acclimated ones. That *Neoceratodus* conforms with this pattern can be seen from Figure 1. The same pattern has been demonstrated in many teleost fish, for example *Leptocottus armatus* (Morris 1961).

Table 3

Comparative response to temperature by Neoceratodus after acclimation at 18°C and 25°C*

Acclimation Temperature	Experimental Temperature	Number of Fish	Mean (ml g^{-1} hr^{-1})	S.D. (ml g^{-1} hr^{-1})	Coefficient of Variation (%)
18	18	6	0·022	0·0038	17
18	25	6	0·030	0·0039	13
25	25	4	0·026	0·0033	13
25	18	4	0·014	0·0025	19

* See Figure 1.

Acclimation in *Neoceratodus* seems to be only partial over the temperature range examined. Data from Mt. Crosby Pumping Station indicate that annual water temperatures range from 11 to 31°C, so the data on metabolic adjustment are mean-

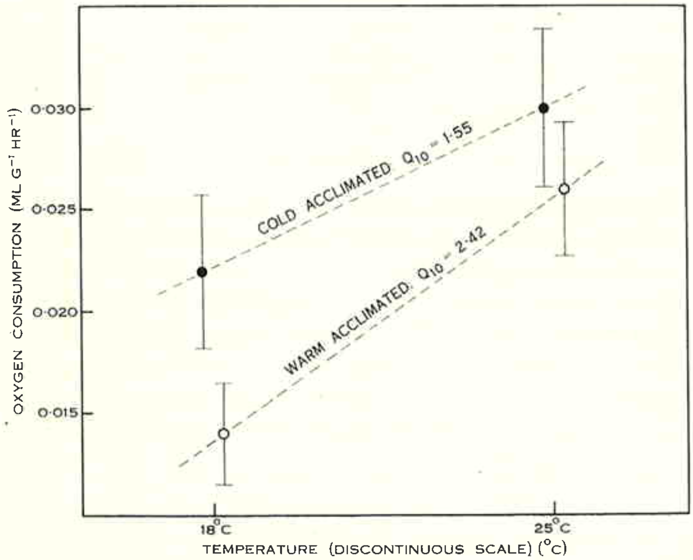

Fig. 1.—Rate–temperature plots for cold acclimated (●) and warm acclimated (○) *Neoceratodus*. Vertical lines equal one S.D. on each side of mean.

ingful in terms of the ecology of the fish. The oxygen consumption at 18°C after a 25°C history compared with that after an 18°C history indicates the degree of winter hardiness. At 25°C little or no acclimation was observed, which suggests that this is close to the temperature preferendum. The water temperature during breeding and development of larvae, in spring–summer (Maclay 1883; Rudel 1935), would be of this order.

For a complete study of the temperature responses of *Neoceratodus*, many fish, preferably juveniles, would be necessary. Lethal limits and the temperature preferendum could be established, and acclimation examined over a wider range of temperatures. The already referred to difficulty of obtaining fish of a suitable size, along with other considerations, will make a thorough study a matter of considerable difficulty.

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