Bull. Inst. Zool., Academia Sinica 22(1): 43-48 (1983)

THE OXYGEN CONSUMPTION BY FORMOSAN ABALONE, *HALIOTIS DIVERSICOLOR SUPERTEXTA* LISCHKE, DURING DECLINE OF AMBIENT OXYGEN[1]

RONG-QUEN JAN AND KUN-HSIUNG CHANG

Institute of Zoology, Academia Sinica, Taipei, Taiwan 115, Republic of China

(Received August 26, 1982)

Rong-Quen Jan and Kun-Hsiung Chang (1983) The oxygen consumption by Formosan abalone, *Haliotis diversicolor supertexta* Lischke, during decline of ambient oxygen. *Bull. Inst. Zool., Academia Sinica* 22(1): 43-48. The respiratory study of Formosan abalone, *Haliotis diversicolor supertexta* Lischke, was based on measurements on the dissolved oxygen contents at 23°C and 35‰ salinity in close systems. The oxygen consumption rate R (mgO_2/individual/hour) was dependent on body weight of the specimen W (g), and oxygen content C (mgO_2/l) in the sea water. That is, when oxygen content maintained above $4.4168\,W^{0.09933}$, the oxygen consumption rate was $0.1563\,W^{0.6125}$; however, when the content declined below that level, R would change in accordance with a value of $0.02721\,W^{0.4956}\,C^{1.1769}$.

The small abalone, *Haliotis diversicolor supertexta* Lischke, is a common prosobranch mollusc on rocky subtidal shores of eastern and northern Taiwan. The cultivation of this abalone has been developed in recent years. But basic physiological and ecological data are still wanting. Since oxygen levels in most marine environments are adequate to sustain life, respiratory studies may provide an indicator of the availability of oxygen to this animal.

In spite of the increasing number of studies made during recent years on the relationship between oxygen consumption by marine animals and oxygen tension in sea water (Bayne, 1971a; Bayne and Livingstone, 1977; Taylor and Brand, 1975), there are still relatively few data which can be used to relate these parameters to a weight range of individuals. Details of these data are of interest both for understanding of the ecology of a species, and also in the management of water quality for artificial cultivation.

In this paper an attempt is made to determine the relationship among animal size, oxygen tension and oxygen consumption of abalones.

MATERIALS AND METHODS

Abalones, *Haliotis diversicolor supertexta* Lischke, were collected by scuba diving at 8-10 m depth off Gichi, on the mid-eastern part of Taiwan, in the summer of 1981. They were taken to the laboratory of the Institute, and transferred to aquaria containing boulders. The abalones were held in the laboratory for more than 50 days prior to experimentation.

In view of the findings of Jan *et al.* (1981a; 1981b), that the magnitude of oxygen consumption of abalone was influenced by environmental factors such as a normal light cycle, light intensity, and presence or absence of food, experiments were carried out in sealed containers (0.8 litres for large, 0.4 litres for small individuals) without food supply and maintained at a constant light intensity of 500 lux.

1. Paper No. 235 of the Journal Series of the Institate of Zoology, Academia Sinica.

Samples of different weight groups were acclimated at 23°C for a week before experimentation, then transferred to containers in which the sea water had been aerating for two hours. After 15 minutes' stagnation, the container was sealed, and oxygen content was measured once every 30 minutes with a Weston and Stock model 33 dissolved oxygen probe connecting to a Rexnord model 650 Multianalyzer. The probe was calibrated every 24 hours by Winkler's method (Taras, 1971).

The result of a preliminary experiment shows the oxygen consumption of abalones to be dependent on the oxygen content only when this dropped to a level similar to Tang's "critical pressure" (Tang. 1933), or *Pc* of other report (Prosser, 1966). *Pc* is replaced here by a critical content (*Cc*) in mg O_2/l, and its value for abalones of different weight groups could be prepared by free hand method. Then data were analyzed according to the oxygen content, that is, when the oxygen content in the sea water has remained above *Cc*, the relationship between wet body weights of abalones and their oxygen consumption rates is determined according to the power equation (allometric equation), $R=aW^b$, where R is the oxygen consumption rate in mg O_2/individual/hour, W is the wet body weight in *g*, a is the intercept, and b is a constant relating the oxygen consumption to weight. When the oxygen content decreases below *Cc*, it is assumed that $R=aW^bC^d$, where C is the oxygen content in mg O_2/l, would fit the relationship among the three factors.

RESULTS

Oxygen consumption rates

The oxygen consumption rates of abalones of different body weights are shown in Fig. 1. For the oxygen content in the sea water remained above *Cc*, the linear relationship between the logarithm of oxygen consumption rates and wet body weights were calculated. The regression shows that

$$R=0.1563W^{0.6125} \qquad r=0.9988 \quad (1)$$

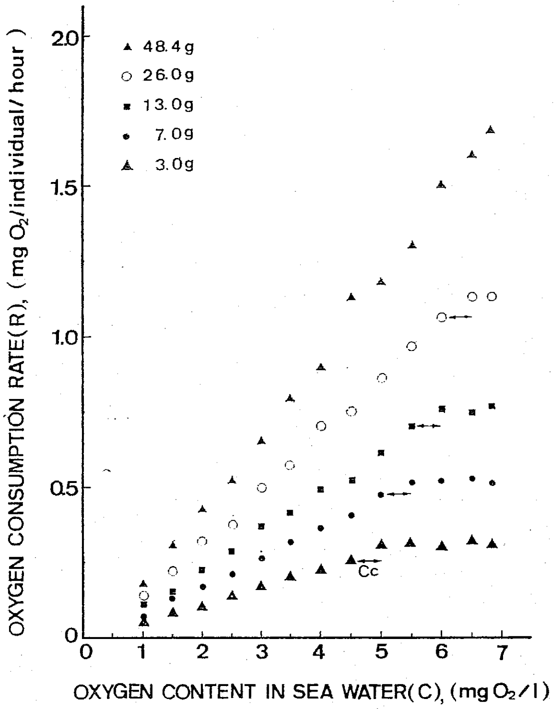

Fig. 1. The oxygen consumption of abalones of different weight groups in declining oxygen content of sea water at 23°C and 35‰ salinity.

The relationship among oxygen consumption, wet body weight, and oxygen content of sea water when the oxygen content declines below *Cc*, shows that

$$R=0.0271W^{0.4956}C^{1.1769} \qquad r=0.9707 \quad (2)$$

The regression is calculated from natural logarithm transformed data. Regression statistics in detail is shown in Table 1.

TABLE 1

Statistics for multiple regression of the equation $R=0.02721\ W^{0.4956}\ C^{1.1769}$

Regression sum of squares	41.241
Residual sum of squares	2.5317
Total sum of squares	43.7727
F-ratio (Regression)	423.531
Degrees of freedom	2 & 52
Number of cases	55
Number of independent variables	2

TABLE 2
Lethal dissolved oxygen (LDO) for abalones of different body weights.

Body weight (g)	48.4	26.0	13.0	7.0	3.0
Number of individuals	3	5	7	12	15
$\overline{LDO} \pm SD$ (mgO_2/l)	0.60±0.03	0.45±0.04	0.41±0.03	0.35±0.03	0.32±0.03

Relationship between *Cc* and body weight

Since equation (1) can be written as

$$R=0.1563\,W^{0.6125}C^{0} \qquad (1')$$

the quantity of *Cc* for abalone of a given weight is derived, as follows:

Assume that eq. (1′)=eq. (2) at *Cc*, that is

$$0.1563\,W^{0.6125}C^{0}=0.02721\,W^{0.4956}C^{1.1769} \qquad (3)$$

then we have

$$C=4.4168\,W^{0.09933} \qquad (4)$$

where C ($mg\,O_2/l$) is the *Cc* value desired.

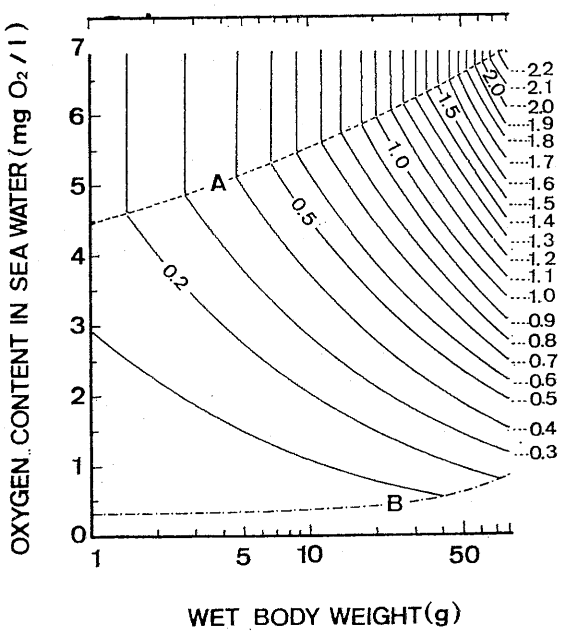

Fig. 2. Isopleth oxygen-consumption diagram of dissolved oxygen content to wet body weight of abalone. The contours represent the magnitude of oxygen consumption rate in mgO_2/individual/hour. 'A'-line shows the relationship between critical dissolved oxygen content and wet body weight, 'B'-line shows the estimated lethal dissolved oxygen content.

Lethal dissolved oxygen (LDO)

At 23°C, 35‰ salinity, the LDO for abalones are shown in Table 2. It is found the LDO to be correlated with body weights. The relationship is

$$C=0.006W+0.32 \qquad (5)$$

Isopleth oxygen-consumption diagram relating dissolved oxygen content to wet body weight of abalone is prepared (Fig. 2). This diagram is made from equations (1), (2), (4) and (5). A-line made from eq. (4) shows the trend of *Cc* for abalones, viz., when the body weight of abalone increases, the *Cc* value would also increase. B-line shows the spectrum of LDO due to different body weights.

DISCUSSION

Many animals (designated oxy-regulators) in reduced environmental oxygen regulate their oxygen consumption down to some critical pressure (*Pc*), below which the oxygen consumption declines rapidly (Prosser, 1966). The critical pressure in this process is also termed the critical oxygen tension (Bishop, 1950), or incipient limiting level (Fry, 1957). In other animals (designated oxy-conformers) the oxygen consumption goes down as the environmental oxygen concentration decreases (Prosser, 1966). However, the respiratory mode for an animal is variable. For example, during the decline of oxygen tension, *Mytilus edulis* either regulate (oxy-regulator) or fail to regulate (oxy-conformer) oxygen consumption depending on the availability of food (Bayne, 1971b).

In the present study we found that the value of *Cc* (cf. *Pc*) for *Haliotis diversicolor supertexta* increased when the body weight of individual increased. A relationship as $Cc=4.4168\,W^{0.09933}$ existed between the two factors. It is to say, under the present experimental condition abalones of body weight below 78.2 g are oxy-regulators, whereas the individual of body weight above 78.2 g would be a oxy-conformer, because the possible Cc derived from experimental results is higher than 6.81 mg O_2/l, the oxygen saturation level.

Studies concerning the effect of declining oxygen tension on oxygen uptake in marine animals and the treatment of data derived from experiment has been undertaken by Tang (1933). The simple hyperbolic expression prepared by Tang, namely, $Q_{O_2}=P_{O_2}/(K_1+K_2P_{O_2})$, where Q_{O_2}: weight specific oxygen consumption, P_{O_2}: oxygen tension, K_1, K_2: constants, to describe the relationship between the rate of oxygen uptake and ambient oxygen tension, was later quoted by Prosser (1966), and elaborated by Bayne for the proposition of "oxygen-dependence index, viz., K_1/K_2" (1971; 1973). Besides, a quadratic polynomial equation, namely, $Q_{O_2}=B_0+B_1P_{O_2}+B_2P_{O_2}^2$, where B_1 and B_2 were constants, was later suggested to describe the relationship by Mangum and Van Winkle (1973) and re-evaluated by them in 1975, for this equation was good in providing statistical fittness, ease of computation, and useful parameters for interspecific comparisons. Both of above methods in application make use of Q_{O_2}, namely, the "weight specific oxygen consumption". When V_{O_2} is the oxygen consumption rate of individuals, the relationship $V_{O_2}=aW^b$ would exist. And the original definition shows that $Q_{O_2}=V_{O_2}/W$ (Tang, 1933), so that Q_{O_2} would be equal to aW^{b-1}, which, as V_{O_2} is, is highly weight-dependent. Therefore it is apparent that the relationship and its derivation treated by above method can only be related between factors to animals of specific body weights. To minimize variations due to differences in weight between individuals, Bayne and Livingstone (1977) tried to sellect specimens with a narrow range of length and relate all V_{O_2} determinations to $W^{0.7}$.

To meet the same problem, we consider "body weight" as a parameter in data treatment in the present study, and suggest that a relationship, $R=aW^bC^d$, exists among oxygen consumption R (cf. V_{O_2}), animal body weight W, and ambient oxygen content C. This regression model also meets the criteria proposed by Van Winkle and Mangum (1975) to model evaluation, by (a) fitting data well, (b) easily computed, and (c) suitable for animal from perfect conformity to perfect regulation. In this regression, d may be used as an index of an animal's ability to regulate its rate of oxygen uptake in declining oxygen contents. When $d=0$, the animal is a prefect oxy-regulator, whereas when $d=1$, the animal is a perfect oxy-conformer. To the latter case, an example also exists in Bayne's study (1971a). Though in the text the author did'nt directly indicate this quantitative phenomenon, in his paper Figs. 2 and 3, describing oxygen consumption of *Arctica*, showed a relationship as $Q_{O_2}=aW^bP_{O_2}+S$, where S is a varible independent of P_{O_2}, among these factors. In this case that the rate of oxygen consumption was dependent on the environment indicates that this species is a metabolic conformer to oxygen. As to the exponent on P_{O_2}, it might be taken as 1, to imply a similar relationship as $R=aW^bC^1$ as suggested in the present study.

To a general oxy-regulator, a bi-phase response usually occurs in declining oxygen contents. In this case a distinct Cc might exist, and, when the ambient oxygen contents remain above Cc, the oxygen consumption rate would maintain nearly constant, that is, with $d=0$ in the regression. In case that the ambient oxygen contents drop below Cc, the conformity would then be triggered and the oxygen consumption rate would decrease according to the existing oxygen contents. The oxygen consumption of *H. diversicolor supertexta* in present study shows an example of this bi-phase response.

During experiment, it was observed that when the oxygen content fell below a certain level (which varied according to animal's size), the abalone would climb toward the surface of the water, then remain quiescent if it failed to escape. The same avoidance behaviour had been found before; in one instance it was observed a large number of abalones left their shelters, moved toward the wall of aquarium, and climbed up to water surface when the oxygen content in the sea water fell to 3.7 mg O_2/l (personal observation). It is not clear whether avoidance behaviour in response to low oxygen constitutes a highly directed form of behaviour. It may result simply from increased locomotor activity with more random movement, which is satisfied by discovery of improved oxygen conditions. However, implicit in a behavioural response to low oxygen may be some means of detecting low oxygen water and this could have survival value.

The physiological response to declining oxygen content is still obscure in abalone. It was observed that *H. d. supertexta* would survive for 4–8 hours, with a low uptake of oxygen, when dissolved oxygen fell below 0.5 mg O_2/l. Although anaerobiosis of some molluscs, mostly in bivales (Wijsman, 1975; Wijsman and de Zwaan, 1976; Zs-Nagy and Ermini, 1972), does occur. It is difficult to evaluate the degree to which this abalone utilizes anaerobic processes, since bivalves are filter-feeders and withdraw oxygen as well as retain food from the water flow resulting by cilliary movements.

To meet water quality management's needs in mariculture, the oxygen-consumption values derived from data obtained at 23°C are prepared in Fig. 2. Furthermore, a starved abalone at night may consume more oxygen by approximately 20% than that indicated by the diagrams (Jan *et al.*, 1981a).

Acknowledgements: This research was sponsored by the National Science Council, Republic of China. The authors wish to thank Dr. J. A. Colin Nicol, for invaluable criticism of the manuscript, Dr. Yao-Sung Lin, for help in data analysis, Mr. Kwang-Tsao Shao and Mr. Chang-Po Chen, for useful advice throughout this study.

REFERENCES

BAYNE, B. L. (1971a) Oxygen consumption by three species of lamellibranch mollusc in declining ambient oxygen tension. *Comp. Biochem. Physiol.* **40A**: 955–970.

BAYNE, B. L. (1971b) Ventilation, the heart beat and oxygen uptake by *Mytilus edulis* L. in declining oxygen tension. *Comp. Biochem. Physiol.* **40A**: 1065–1085.

BAYNE, B. L. (1973) The responses of three species of bivalve mollusc to declining oxygen tension at reduced salinity. *Comp. Biochem. Physiol.* **45A**: 793–806.

BAYNE, B. L. and D. R. Livingstone (1977) Responses of *Mytilus edulis* L. to low oxygen tension: Acclimation of oxygen consumption. *J. Comp. Physiol.* **114**: 129–142.

BISHOP, D. W. (1950) Respiration and metabolism. In *Comparative animal physiology.* W. B. Saunders Company, Philadelphia. 209–289.

FRY, F. E. J. (1957) The aquatic respiration of fish. In *The physiology of fishes.* (M. E. Brown, ed.). Academic Press, New York. **1**: 1–63.

JAN, R. Q., K. T. SHAO and K. H. CHANG (1981a) A study of diurnal periodicity in oxygen consumption of the small abalone (*Haliotis diversicolor supertexta* Lischke). *Bull. Inst. Zool., Academia Sinica* **20**(1): 1–8.

JAN, R. Q., K. T. SHAO and K. H. CHANG (1981b) Extract of sea lettuce *Ulva* reduces oxygen consumption of abalone (*Haliotis diversicolor supertexta* Lischke). *Bull. Inst. Zool., Academia Sinica* **20**(1): 83–85.

MANGUM, C. P. and W. VAN WINKLE (1973) Responses of aquatic invertebrates to declining oxygen conditions. *Am. Zool.* **13**: 529–541.

PROSSER, C. L. (1966) Oxygen: respiration and metabolism. In *Comparative animal physiology.* (C. L. Prosser and F. A. Brown, Jr., ed.). W. B. Saunders Company, Philadelphia. 153–197.

TANG, P. S. (1933) On the rate of oxygen consumption by tissues and lower organisms as a function of oxygen tension. *Quart. Rev. Biol.* **8**: 260–274.

TARAS, M. J. (1971) Azide modification of Winkler's method for the dissolved oxygen analysis. In *Standard methods for the examination of water and waste water.* 13th ed. Amer. Publ. Health Association. 440–453.

TAYLOR, A. C. and A. R. BRAND (1975) A comparative study of the respiratory responses of the bivalves *Arctica islandica* and *Mytilus edulis* to declining oxygen tension. *Proc. R. Soc. Lond.* **190 B**: 443–456.

WIJSMAN, T. C. M. (1975) pH fluctuations in *Mytilus edulis* L. in relation to shell movements under aerobic and anaerobic conditions. *Proc. 9th Europ. Mar. biol. Symp. Aberdeen Univ. Press, Aberdeen.* 139-149.

WIJSMAN, T. C. M. and A. DE ZWAAN (1976) Review: Anaerobic metabolism in bivalvia. *Comp. Biochem. Physiol.* **54A**: 313-324.

VAN WINKLE, W. and C. P. MANGUM (1975) Oxyconformers and oxyregulators: A quantitative index. *J. exp. mar. biol. ecol.* **17**: 103-110.

ZS-NAGY, I. and M. ERMINI (1972) ATP production in the tissues of the bivalve *Mytilus galloprovincialis* (Pelecypoda) under normal and anoxic conditions. *Comp. Biochem. Physiol.* **43A**: 593-600.

九孔耗氧量與水中溶氧量關係之探討

詹 榮 桂　　張 崑 雄

本報告的主旨在探討九孔 *Haliotis diversicolor supertexta* Lischke 在水中溶氧遞減的情況下，耗氧量的變化情形。在水溫 23°C，鹽度爲 35‰ 的海水裏，九孔的耗氧量 R (mg O_2/individual/hour) 與九孔的濕重 W (g)，以及海水中的溶氧量 C (mg O_2/ℓ) 等兩因子有關；亦卽，當水中溶氧量維持在 $4.4168W^{0.09933}$ 以上時，九孔的耗氧量爲 $0.1563W^{0.6125}$，當溶氧量降到 $4.4168W^{0.09933}$ 以下時，九孔的耗氧量爲 $0.02721W^{0.4956}C^{1.1769}$。此結果並另以九孔的耗氧等高線圖表示。