

Effects of temperature and salinity on the standard metabolic rate (SMR) of the caridean shrimp *Palaemon peringueyi*

E.L. Allan, P.W. Froneman and A.N. Hodgson

Abstract

The standard metabolic rate (SMR) of the caridean shrimp *Palaemon peringueyi* to changes in temperature (15–30 °C), salinity (0–45‰) and a combination thereof was investigated. The rate of oxygen consumption of the shrimp was determined using a YSI oxygen meter. At a constant salinity of 35‰ the respiration rate of *P. peringueyi* increased with an increase in temperature and ranged between 0.260 and 0.982 $\mu\text{l O}_2 \text{ mg wwt}^{-1} \text{ h}^{-1}$. The Q_{10} value over the temperature range 15–25 °C was estimated at 3.13. At a constant temperature of 15 °C the respiration rate of *P. peringueyi* also increased with an increase in salinity and ranged between 0.231 and 0.860 $\mu\text{l O}_2 \text{ mg wwt}^{-1} \text{ h}^{-1}$. For combination experiments the absence of any significant difference in the respiration rate of *P. peringueyi* at the four temperatures over the salinity range 15–35‰ suggests that the shrimp is well adapted to inhabiting environments characterised by variations in salinity and temperature such as those encountered within the middle and lower reaches of permanently open estuaries with substantial freshwater inflow. On the other hand, the total mortality of the shrimp recorded at salinities < 5‰ at all four temperatures suggests that the upper distribution of the shrimp may reflect physiological constraints. Similarly, the increase in the respiration rate of the shrimp at the four temperatures at salinities > 35‰ suggests that the shrimp may experience osmotic stress in freshwater deprived permanently open and intermittently open estuaries where hypersaline conditions may develop.

1. Introduction

Intrinsic factors such as body size and moulting stage ([Schmidt-Nielsen, 1983](#) and [Emmerson, 1985](#)) and extrinsic factors such as temperature, dissolved oxygen and salinity ([Hagerman and Weber, 1981](#), [Schmidt-Nielsen, 1983](#), [Achituv and Cook, 1984](#) and [Spanopoulos-Hernández et al., 2005](#)) play important roles in the biology of many crustacean species. In crustaceans respiration generally increases with an increase in temperature, which has been observed in many species of shrimp including *Litopenaeus stylirostris* ([Spanopoulos-Hernández et al., 2005](#)) and *Penaeus chinensis* ([Chen and Nan, 1993](#)) as well as copepods such as *Pseudodiaptomus hessei* ([Isla and Perissinotto, 2004](#)). The response of crustaceans to changes in salinity are, however, more complex ([Kinne, 1966](#)). Standard metabolic rates may be influenced in four different ways: (1) increased in subnormal salinities and/or reduced in supranormal salinities, (2) increased both in sub- and supranormal salinities, (3) reduced both in sub- and supranormal salinities, (4) essentially unaffected ([Kinne, 1966](#)). In estuarine systems abiotic variables such as temperature and salinity can dramatically change across spatial and temporal scales ([Kirkpatrick and Jones, 1985](#) and [Rowe, 2002](#)). Abiotic factors, particularly salinity, may thus play an important role in determining species distributions within estuarine systems ([Wooldridge, 1999](#) and [Rowe, 2002](#)).

The caridean shrimp *Palaemon peringueyi* (previously known as *Palaemon pacificus*) ([MacPherson, 1990](#)) is a temperate species that occurs along the southern African coastline from Walvis Bay (west coast) to Kosi Bay (east coast), although it tends to be more common toward the southeast and south coasts ([de Villiers et al., 1999](#)). *P. peringueyi* breed in marine coastal waters but stage 6 and post-larvae will migrate from offshore spawning grounds to sheltered nursery habitats of estuaries or rock pools ([Emmerson, 1986](#) and [de Villiers et al., 1999](#)). Within estuarine systems the highest densities of *P. peringueyi* can be found within eelgrass beds (*Zostera capensis*) where their abundances may be up to 400 individuals per m² ([Emmerson, 1986](#) and [Wooldridge, 1999](#)). *P. peringueyi* is not dependent on estuaries to complete its life cycle, however their presence in large numbers suggests they are likely to play an important role in estuarine food webs ([Wooldridge, 1999](#)).

Within estuaries *P. peringueyi* is a conspicuous component of the hyperbenthos of the lower and middle reaches of both permanently and intermittently open systems ([de Villiers et al., 1999](#), [Kibirige and Perissinotto, 2003](#), [Bernard and Froneman, 2004](#), [Froneman, 2004](#) and [Kemp and Froneman, 2004](#)). The shrimp is, however, virtually absent from the upper reaches of these estuaries ([Kibirige and Perissinotto, 2003](#) and [Bernard and Froneman, 2004](#)). The absence of the shrimp from the upper reaches may reflect physiological constraints. *P. peringueyi* have been shown to remain active and capable of growth at salinities between 10‰ and 50‰ and at temperatures between 10 and 30 °C ([Robertson, 1984](#) and [de Villiers et al., 1999](#)). Salinity extremes and lower temperatures may be tolerated, however, only for limited periods while temperatures greater than 30 °C tend to be lethal ([Robertson, 1984](#) and [de Villiers et al., 1999](#)). Both temperature and salinity are important physical variables that are known to directly affect physiological responses of most invertebrate species ([Schmidt-Nielsen, 1983](#)). It has been shown that temperature directly affects the rate of physiological processes while salinity places an osmoregulatory demand on aquatic organisms ([Schmidt-Nielsen, 1983](#) and [Spanopoulos-Hernández et al., 2005](#)). Changes in temperature and salinity rarely occur independently of one another ([de Villiers et al., 1999](#)). Despite this little research has been done on the combined effect of temperature and salinity on South African estuarine inhabitants ([de Villiers et al., 1999](#)). Previous studies ([Achituv and Cook, 1984](#) and [Emmerson, 1985](#)) have only investigated the effect of one physical variable (temperature) on the oxygen consumption rate of *P. peringueyi* (in their studies *P. pacificus*). The main aim of the study, therefore, was to investigate the effect of temperature and salinity and a combination thereof on the standard metabolic rate of the caridean shrimp *P. peringueyi*.

2. Methods

P. peringueyi were collected from the middle reaches of the Kariega estuary (33°40′S; 26°40′E) where the salinity was approximately 35‰. In the laboratory the shrimp were kept in aerated tanks (0.40 m × 0.30 m × 0.12 m) filled with unfiltered seawater (35‰) in a constant environment (CE) room set at the specific experimental temperature with a 12:12 light/dark phase. The shrimp were provided with fish food (protein 47.0%, oil 12.5% and fibre 1.5%) daily. The physiological response of adult male and female *P. peringueyi* (carapace length 7.0–11.0 mm; wet weight 92.6–199.7 mg) to changes in temperature (15–30 °C), salinity (5–45‰) and a combination thereof were investigated in 2005. The sex of the shrimp was determined by the presence (male) or absence (female) of an appendix masculine (a.m.) on the endopod of the second pleopod ([Bernard and Froneman, 2004](#)).

2.1. Temperature

The effect of temperature on the metabolic rate of the shrimp was investigated within a range of seasonal estuarine temperatures (15, 20, 25 and 30 °C) at a constant salinity of 35‰. The shrimp were acclimated at the experimental temperature overnight prior to each experiment by gradually adjusting the temperature (0.5 °C/h) of the CE room. The temperatures during the experiments were maintained within ± 0.1 °C by using a water bath. For each temperature, four replicates were prepared each containing one shrimp and a control flask that did not contain a shrimp. Each experiment was repeated 3 times with new individuals.

The oxygen consumption rate was determined by sealing, with a lid and petroleum jelly, one shrimp in a 100 ml conical flask for 1 h. The experiment was carried out within the dark so as to minimise disturbance of the shrimp. Observations conducted during the incubation indicated that the shrimp largely remained motionless during the experiments. As consequence we have assumed that the respiration rates measured constitute the standard metabolic rate (SMR) of *P. peringueyi*. The oxygen concentration was measured using a YSI 550 DO oxygen probe and meter. The difference between the oxygen concentrations of the control flask and the experimental flasks was used to determine the oxygen consumption rate of each shrimp. Immediately after the experiment the wet weight (precision 0.0001 g) of the shrimp was determined using a Sauter AR 100 microbalance after excess water had been removed using blotting paper. The mass specific oxygen consumption rates of the shrimp were then expressed as microliter of oxygen consumed per milligram of wet weight per hour ($\mu\text{l O}_2 \text{ mg wwt}^{-1} \text{ h}^{-1}$).

The Q_{10} value of the shrimp was determined by using the equation $Q_{10} = (V_2/V_1)^{10/T_2 - T_1}$ in which V_2 and V_1 are the specific physiological rates at the respective temperatures T_2 and T_1 (Schmidt-Nielsen, 1983).

2.2. Salinity

The effect of salinity on the oxygen consumption rate of the shrimp was investigated at five salinities (5‰, 15‰, 25‰, 35‰ and 45‰) at a constant temperature of 15 ± 0.1 °C. The salinity required was obtained by diluting sterilised seawater with double distilled water. The shrimp were acclimated at the experimental salinity overnight prior to the experiment. The procedure employed was similar to that described above.

2.3. Temperature and salinity

The combined effects of salinity and temperature on the oxygen consumption rate of the shrimp were investigated over a range of temperatures (15, 20, 25 and 30 °C) and salinities (5‰, 15‰, 25‰, 35‰ and 45‰) using the method described earlier.

2.4. Statistical analysis

All analysis was performed in Statistica (version 7.0) employing a one-way ANOVA followed by a post hoc Scheffe test with a significance level of 5%. For all salinity and temperature combination experiments analysis was performed in Statistica utilising a factorial ANOVA for multiple independent variables.

3. Results

As there was no significant difference in the oxygen consumption rates between male and female *P. peringueyi* ($p > 0.05$) values were pooled.

3.1. Temperature

The oxygen consumption rates of *P. peringueyi* at 35‰ ranged between 0.260 and 0.982 $\mu\text{l O}_2 \text{ mg wwt}^{-1} \text{ h}^{-1}$ and increased with an increase in temperature (Fig. 1). The Q_{10} value was estimated at 3.13 over the temperature range 15 to 25 °C. A significant difference was observed in the oxygen consumption rates of the shrimp between 15, 20 and 30 °C ($p < 0.05$). However, there was no significant difference between 20 and 25 °C as well as 25 and 30 °C ($p > 0.05$).

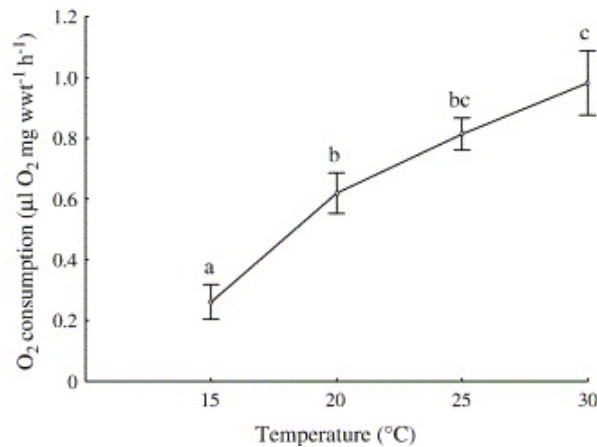


Fig. 1. The effect of temperature at a constant salinity (35‰) on the oxygen consumption rates (mean \pm S.E.) of *Palaemon peringueyi*. Different letters denote a significant difference ($p < 0.05$). $n = 9-11$ for each treatment.

3.2. Salinity

At a constant temperature of 15 °C over the salinity range 5–45‰, the oxygen consumption rates of the shrimp ranged between 0.231 and 0.860 $\mu\text{l O}_2 \text{ mg wwt}^{-1} \text{ h}^{-1}$ and increased with an increase in salinity (Fig. 2). No significant difference was observed in the oxygen consumption rates of the shrimp between 5‰ and 15‰ as well as 25‰ and 35‰ ($p > 0.05$). There were, however, significant differences in the oxygen consumption rates between 5/15‰, 25/35‰ and 45‰ ($p < 0.05$).

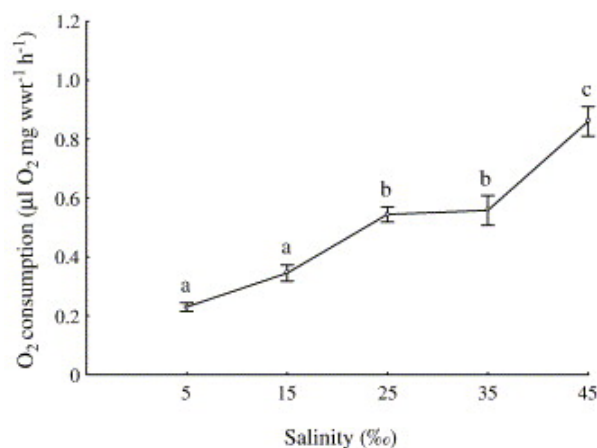


Fig. 2. The effect of salinity at a constant temperature (15 °C) on the oxygen consumption rates (mean \pm S.E.) of *Palaemon peringueyi*. Different letters denote a significant difference ($p < 0.05$). $n = 11-12$ for each treatment.

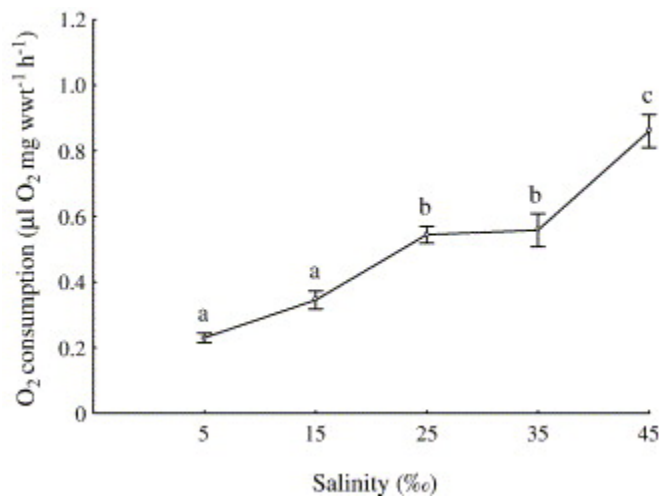


Fig. 2. The effect of salinity at a constant temperature (15 °C) on the oxygen consumption rates (mean \pm S.E.) of *Palaemon peringueyi*. Different letters denote a significant difference ($p < 0.05$). $n = 11-12$ for each treatment.

3.3. Temperature and salinity

P. peringueyi suffered 100% mortality at salinities $< 5‰$ at all four temperatures. At salinities $> 5‰$ the oxygen consumption rates of the shrimp at the various temperatures increased with an increase in salinity (Fig. 3 and Fig. 4). Over the salinity range 5–25‰ there was no significant difference in the oxygen consumption rates of the shrimp between the various temperatures (Fig. 3). However, at salinities $> 35‰$ the increase in oxygen consumption was more pronounced between temperatures (Fig. 3). The shrimp at each of the four temperatures showed a similar trend with the oxygen consumption rates at 5‰ and 45‰ being significantly different from the remaining values ($p < 0.05$) (Fig. 4). There were no significant differences in the respiration rate of the shrimp at the four temperatures between 15‰ and 25‰ as well as 25‰ and 35‰ ($p > 0.05$) (Fig. 4). The two-factor ANOVA showed that both salinity and temperature had a significant effect on the oxygen consumption of the shrimp ($p < 0.05$ in both cases), however there was no interaction between these two variables ($p > 0.05$).

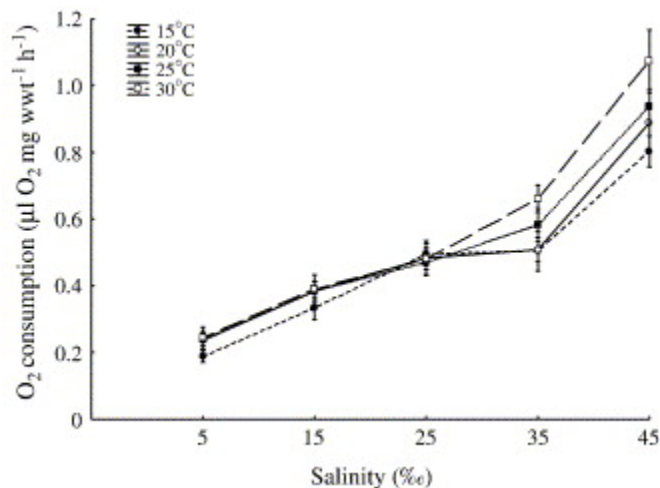


Fig. 3. The combined effect of salinity (5‰, 15‰, 25‰, 35‰ and 45‰) and temperature (15, 20, 25 and 30 °C) on the oxygen consumption rates (mean \pm S.E.) of *Palaemon peringueyi*. Shrimps experienced 100% mortality when incubated at salinities $< 5‰$ at all four temperatures. $n = 9-12$ for each treatment.

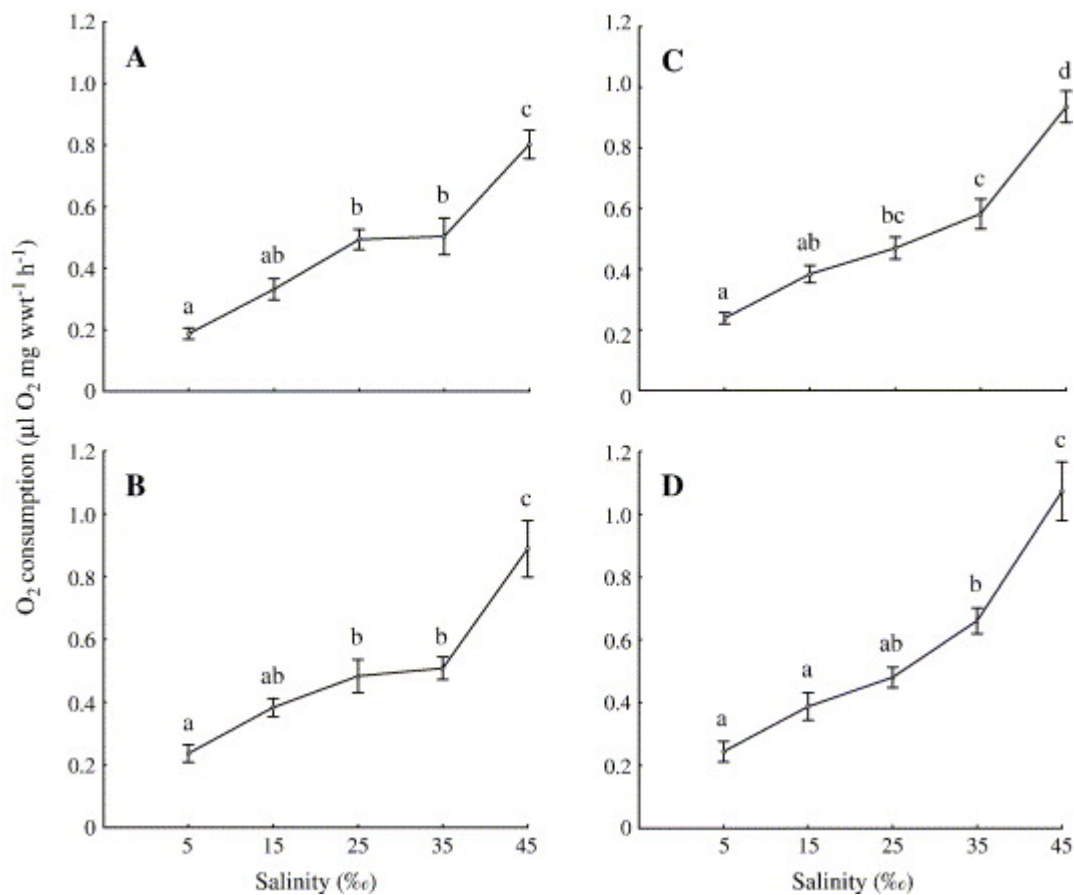


Fig. 4. The effect of salinity on the oxygen consumption rates (mean \pm S.E.) of *Palaemon peringueyi* at 15 °C (A), 20 °C (B) 25 °C (C) and 30 °C (D). Different letters denote a significant difference ($p < 0.05$). $n = 9$ –12 for each treatment.

4. Discussion

The increase in the respiration rate of *P. peringueyi* with the increase in temperature observed during this study corresponds to results obtained in previous studies (Achituv and Cook, 1984 and Emmerson, 1985). As temperature directly affects the rate of all biological processes the increase in respiration rate with an increase in temperature is not surprising (Schmidt-Nielsen, 1983). The oxygen consumption rates obtained in the previous study by Achituv and Cook (1984) were similar to the values obtained within this study, which was expected as both studies used a closed bottle system. However, the values obtained in these studies were approximately double those obtained by Emmerson (1985) in which a continuous flow respirometer was employed. The discrepancy between the results could be due to the use of different methods or different levels of shrimp activity in the respiration chambers. The Q_{10} value of 3.13 obtained over the temperature range 15 to 25 °C at 35‰ was similar (3.12) to that obtained for routine metabolism in a previous study (Emmerson, 1985). It has been shown that within the temperature range that can be tolerated, an increase in 10 °C generally results in a two- to threefold increase in the rate of oxygen consumption (Schmidt-Nielsen, 1983). This Q_{10} value obtained during this study therefore suggests that the shrimp is unlikely to experience thermal extinction in permanently open estuaries where temperatures rarely exceed 25 °C (Grange and Allanson, 1995).

Metabolic responses of crustaceans to changes in salinity are highly variable among species (Kinne, 1966 and Huni and Aravindan, 1985). In this study an increase in salinity was associated with an increase in the respiration rate of *P. peringueyi*. However, the absence of any significant difference in the respiration rate of *P. peringueyi* over the salinity range 15–35‰ suggests that the shrimp is well adapted to

inhabiting environments characterised by variations in salinity and temperature. Such conditions occur in the middle reaches of permanently open estuaries with substantial freshwater inflow. Within these systems salinity fluctuates greatly due to tidal influences (Kirkpatrick and Jones, 1985). On the other hand, when the shrimp were incubated at all four temperatures at salinities $< 5\text{‰}$ the shrimp suffered total mortality. A previous study investigated the salinity tolerance range of *Palaemon affinis* and compared it to that of other *Palaemon* species (Kirkpatrick and Jones, 1985). Kirkpatrick and Jones (1985) found that *Palaemon* species that inhabit marine or brackish water environments are unable to tolerate low salinities which is not surprising if one considers that these species are marine in origin and are therefore not naturally exposed to freshwater. Such mortality at lower salinities suggests that the upper distribution of the shrimp, particularly in permanently open systems characterised by sustained freshwater inflow, may be limited by physiological constraints. Indeed, several studies have demonstrated that *P. peringueyi* is absent from the upper reaches of permanently open estuaries with sustained freshwater inflow (Emmerson, 1986).

The increase in the respiration rate of the shrimp at the four temperatures at salinities $> 35\text{‰}$ suggest that the shrimp may experience osmotic stress in freshwater deprived permanently open and intermittently open estuaries where hypersaline conditions may develop (Allanson and Read, 1995). At salinities $\geq 35\text{‰}$ the increase in the respiration rate of the shrimp is likely to be due to the active removal of rapidly accumulating salts within the shrimp (Schmidt-Nielsen, 1983). As no mortality was observed during the experiments the data show that these shrimp are able to tolerate hypersaline conditions. This is advantageous as they often inhabit closed estuaries or rock pools which can experience high fluctuations in temperature and salinity over 24-h periods (Anger, 1996).

In conclusion, there is strong evidence to suggest that the upper distribution of the shrimp *P. peringueyi* within estuarine systems, especially permanently open and intermittently open systems, may be limited by physiological constraints. The wide tolerance range of the shrimp to a range of temperatures and salinities suggest that it is well adapted to surviving in aquatic systems characterised by variations in salinity and temperature. In particular they are able to withstand hypersaline conditions ($> 35\text{‰}$), which enables them to persist in freshwater deprived permanently open and intermittently open estuaries as well as rock pools.

Acknowledgements

Funding for this project was provided by Rhodes University and the Andrew Mellon Foundation Scholarship. We would like to thank Rhodes University for the use of their facilities and to Benjamin Price for his assistance with the field work. [SES]

References

- Achituv and Cook, 1984 Y. Achituv and P.A. Cook, The influence of temperature variations and thermal pollution on various aspects of the biology of the prawn *Palaemon pacificus* (Stimpson), *J. Exp. Mar. Biol. Ecol.* 74 (1984), pp. 291–302.
- Allanson and Read, 1995 B.R. Allanson and G.H.L. Read, Further comment on the response of Eastern Cape Province estuaries to variable freshwater inflows, *S. Afr. J. Aquat. Sci.* 21 (1995), pp. 56–70.

- Anger, 1996 K. Anger, Salinity tolerance of the larvae and first juveniles of a semiterrestrial grapsid crab, *Armases miersii* (Rathbun), *J. Exp. Mar. Biol. Ecol.* 202 (1996), pp. 205–223.
- Bernard and Froneman, 2004 A.T.F. Bernard and P.W. Froneman, Population dynamics of the caridean shrimp, *Palaemon peringueyi*, in a temperate temporarily open/closed southern African estuary, *Estuar. Coast. Shelf Sci.* 63 (2004), pp. 73–81.
- Chen and Nan, 1993 J.C. Chen and F.H. Nan, Changes of oxygen consumption and ammonia-N excretion by *Penaeus chinensis* Obeck at different temperature and salinity levels, *J. Crustac. Biol.* 13 (1993), pp. 706–712.
- de Villiers et al., 1999 C. de Villiers, A.N. Hodgson and A. Forbes, Studies of estuarine macroinvertebrates. In: B.R. Allanson and D. Baird, Editors, *Estuaries of South Africa*, Cambridge University Press, Cambridge, UK (1999), pp. 167–208.
- Emmerson, 1985 W.D. Emmerson, Oxygen consumption in *Palaemon pacificus* (Stimpson) (Decapoda: Palaemonidae) in relation to temperature, size and season, *Comp. Biochem. Physiol.*, A 81 (1985), pp. 71–78
- Emmerson, 1986 W.D. Emmerson, The ecology of *Palaemon pacificus* (Stimpson) associated with *Zostera capensis*, Setchell, *Trans. R. Soc. S. Afr.* 46 (1986), pp. 79–97.
- Froneman, 2004 P.W. Froneman, Zooplankton community structure and biomass in a southern African temporarily open/closed estuary, *Estuar. Coast. Shelf Sci.* 60 (2004), pp. 125–132.
- Grange and Allanson, 1995 N. Grange and B.R. Allanson, The influence of freshwater inflow on the nature, amount and distribution of seston in estuaries of the Eastern Cape, South Africa, *Estuar. Coast. Shelf Sci.* 40 (1995), pp. 403–420.
- Hagerman and Weber, 1981 L. Hagerman and R.E. Weber, Respiratory rate, haemolymph oxygen tension and haemocyanin level in the shrimp *Palaemon adspersus* Rathke, *J. Exp. Mar. Biol. Ecol.* 54 (1981), pp. 13–20.
- Huni and Aravindan, 1985 A.A.D. Huni and C.M. Aravindan, The effect of salinity on the oxygen consumption of two intertidal crustaceans, *Comp. Biochem. Physiol.*, A 81 (1985), pp. 869–871.
- Isla and Perissinotto, 2004 J.A. Isla and R. Perissinotto, Effects of temperature, salinity and sex on the basal metabolic rate of the estuarine copepod *Pseudodiaptomus hessei*, *J. Plankton Res.* 26 (2004), pp. 579–583.
- Kemp and Froneman, 2004 J.O.G. Kemp and P.W. Froneman, Recruitment of ichthyoplankton and macrozooplankton during overtopping events into a temporarily open/closed southern African estuary, *Estuar. Coast. Shelf Sci.* 61 (2004), pp. 529–537.
- Kibirige and Perissinotto, 2003 I. Kibirige and R. Perissinotto, The zooplankton community of the Mpenjati Estuary, a South African temporarily open/closed system, *Estuar. Coast. Shelf Sci.* 58 (2003), pp. 727–741.
- Kinne, 1966 O. Kinne, Physiological aspects of animal life in estuaries with special reference to salinity, *Neth. J. Sea Res.* 3 (1966), pp. 222–244.

Kirkpatrick and Jones, 1985 K. Kirkpatrick and M.B. Jones, Salinity tolerance and osmoregulation of a prawn, *Palaemon affinis* Milne Edwards (Caridea: Palaemonidae), *J. Exp. Mar. Biol. Ecol.* 93 (1985), pp. 61–70.

MacPherson, 1990 E. MacPherson, The validation of *Palaemon peringueyi* (Stebbing 1915) from South African waters and its relationships with *Palaemon pacificus* (Stimpson 1860) (Decapoda, Palaemonidae), *J. Nat. Hist.* 24 (1990), pp. 627–634.

Robertson, 1984 Robertson, W.D., 1984. Aspects of the ecology of the shrimp *Palaemon pacificus* (Stimpson) (Decapoda, Palaemonidae) in the Bushmans River estuary. M.Sc. thesis, Rhodes University, South Africa.

Rowe, 2002 C.L. Rowe, Differences in maintenance energy expenditure by two estuarine shrimp (*Palaemonetes pugio* and *P. vulgaris*) that may permit partitioning of habitats by salinity, *Comp. Biochem. Physiol., A* 132 (2002), pp. 341–351.

Schmidt-Nielsen, 1983 K. Schmidt-Nielsen, *Animal Physiology: Adaptation and Environment* (5th ed.), University Press, Cambridge (1983).

Spanopoulos-Hernández et al., 2005 M. Spanopoulos-Hernández, C.A. Martínez-Palaciosb, R.C. Vanegas-Pérezc, C. Rosasd and L.G. Rosse, The combined effects of salinity and temperature on the oxygen consumption of juvenile shrimps *Litopenaeus stylirostris* (Stimpson, 1874), *Aquaculture* 244 (2005), pp. 341–348.

Wooldridge, 1999 T.H. Wooldridge, Estuarine zooplankton community structure and dynamics. In: B.R. Allanson and D. Baird, Editors, *Estuaries of South Africa*, Cambridge University Press, Cambridge, UK (1999), pp. 141–166.