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## Journal of Natural History

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tnah20>

### Effects of temperature and salinity on survival and growth of the amphipod *Hyale crassicornis* (Gammaridea, Hyalidae)

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Published online: 15 Aug 2006.

To cite this article: K. H. Tsoi, K. M. Chiu & K. H. Chu (2005) Effects of temperature and salinity on survival and growth of the amphipod *Hyale crassicornis* (Gammaridea, Hyalidae), *Journal of Natural History*, 39:4, 325-336, DOI: [10.1080/0022293042000200077](https://doi.org/10.1080/0022293042000200077)

To link to this article: <http://dx.doi.org/10.1080/0022293042000200077>

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## Effects of temperature and salinity on survival and growth of the amphipod *Hyalé crassicornis* (Gammaridea, Hyalidae)

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(Accepted 19 January 2004)

### Abstract

This study explored the survival and growth of the marine amphipod *Hyalé crassicornis* under different conditions of ambient temperature and salinity in the laboratory. In 96-h exposure experiments at a salinity of 30, *H. crassicornis* tolerated temperatures between 6 and 28°C (>90% survival). The 96-h LT<sub>50</sub> value (median lethal temperature) at high temperature range for the amphipod was 32°C. The values at low temperature range for adults and juveniles were 3.2 and 4.2°C, respectively, indicating that adults have a higher tolerance to low temperature than juveniles. At 25°C, the amphipods tolerated salinities between 10 and 50 (with >80% survival in 96 h). The 96-h LS<sub>50</sub> values at high and low salinity ranges were 56 and 2, respectively. Growth of the juveniles from instars 1 to 6 was determined under different combinations of temperature and salinity. Growth rate of juveniles cultured at 25°C and a salinity of 20 was the highest (0.114 mm day<sup>-1</sup>) among the combinations of 15–25°C and 10–40 salinity. The moult increment of body length was affected by both temperature and salinity. Yet the intermoult duration of the amphipods was affected by temperature only but not by salinity.

**Keywords:** Amphipod, *Hyalé crassicornis*, Gammaridea, Hyalidae, temperature, salinity, growth, survival

### Introduction

Environmental variables exert a significant impact on the physiology of all organisms. Temperature and salinity are generally regarded as the two major environmental determinants affecting the survival and growth of marine invertebrates (Kinne 1970, 1971). For instance, Brown and Bert (1993) showed that temporal variations in temperature and salinity limited the survival of juvenile stone crabs *Menippe adina* Williams and Felder, 1986. Both survival and growth of the penaeid shrimp, *Penaeus chinensis* (Osbeck, 1765), were affected by salinity and temperature (Chen et al. 1995, 1996).

Biological knowledge of environmental tolerance and growth is essential to the development of optimal culture conditions for animals (Hardy et al. 1994). Many marine invertebrates have specific temperature or salinity requirements at different developmental

stages (Kinne 1970, 1971; Thomas and Rice 1992; Charmantier and Charmantier-Daures 1994; Guerin and Stickle 1997a). Understanding of the physiological requirements and tolerance limits in different growth phases of animals to environmental conditions will be helpful in further studies on their life history and population distributions. Such knowledge is also essential to the development of sensible pollution indices for the evaluation of environmental deterioration (Rosas and Ramirez 1993; Alcaraz et al. 1997). For instance, Alcaraz et al. (1997) reported that post-larvae of the white shrimp *Penaeus setiferus* (Linnaeus, 1767) had a lower tolerance to thermal stress when the animals were exposed to nitrogenous contaminants such as ammonia and nitrite.

The amphipod *Hyale crassicornis* (Haswell, 1880) (Gammaridea, Talitroidea, Hyalidae) is distributed in intertidal areas of Kiama, New South Wales, Cape Naturaliste and Western Australia (Barnard 1974). This species can also be found beneath rocks and pebbles, often associated with seaweed in the intertidal zone of Tolo Harbour, Hong Kong (own observation). Yet, information on the distribution of the species in South-East Asia is limited. Few studies on hyalid amphipods in Hong Kong waters have been undertaken (Moore 1986). Jiang and Zhou (1982) and Moore (1986) recorded four species of the genus *Hyale* found in Hong Kong but none of them was identified as *H. crassicornis*.

Amphipods have been suggested to be good biological indicators for the detection of early environmental degradation (Zanders and Rojas 1992). Interest has arisen in developing *H. crassicornis* as a pollution indicator organism in Hong Kong waters but biological knowledge of this species is very limited. This study aims to: (1) investigate the survival of the amphipod at different temperatures and salinities, and (2) elucidate the relationships between its growth and these two environmental variables. Such information would enhance our understanding of the biology of this amphipod and assist the development of pollution bioassays.

## Material and methods

### *Survival at different temperatures and salinities*

**Acclimation.** Amphipods were collected from Tolo Harbour, Hong Kong and maintained in three 3000-litre outdoor culture tanks at the Marine Science Laboratory of The Chinese University of Hong Kong. The tanks contained natural sea water with a turnover rate of  $\sim 2600$  l day<sup>-1</sup>. The animals were chosen randomly for experiments. Only physically intact and active individuals were selected. Adults and juveniles were separated according to their body length and secondary sexual characters. Individuals with body length < 3 mm and showing no development of sexual characters were defined as juveniles.

Amphipods were acclimated in 500-ml glass beakers filled with well-aerated artificial sea water (Instant Ocean®) for about 1 week before any experiments were undertaken. No more than 10 individuals were raised in each beaker. The acclimation conditions were standardized under a 14:10 h L:D regime at light density between 850 and 1200 lm m<sup>-2</sup>. Temperature, salinity, pH and dissolved oxygen were maintained at 24–26°C, 29–32, 7.0–8.5 and 4.7–6.8 mg l<sup>-1</sup>, respectively. These parameters were monitored every 2 days when  $\sim 250$  ml of the cultured medium was exchanged with well-aerated artificial sea water. The amphipods were fed with four or five pieces (1–2 mm<sup>3</sup>) of freeze-dried krill after each water exchange. Two pieces of the green algal thallus *Ulva lactuca* (Linnaeus, 1753) (2 cm<sup>2</sup>) were provided as clinging substratum and supplementary food source. Any thallus piece was

replaced when it was severely grazed. Faecal matter, food residue, exuviae and any undesirable algae were removed during water exchange.

*Lethal tests.* To investigate temperature effects, the amphipods were exposed to 0, 4, 6, 7, 8, 10, 12, 14, 20, 25, 30, 31, 32, 33, 34 and 35°C at a salinity of 30 for 96 h in an environmental chamber. After acclimation, 10 amphipods were randomly selected and placed in a 500-ml beaker. A total of 50 individuals (adult or juvenile) in five replicates was tested for each temperature. Temperature was slowly adjusted from 25°C to the experimental temperature at the rate of 2–5°C h<sup>-1</sup> for minimizing any drastic change of environmental conditions. No food was provided during the experimental period. All dead amphipods and exuviae were removed from the beakers during the daily inspection. The physical parameters of the medium were monitored daily during the experimental period. About 250 ml of medium was renewed every 48 h. Mortality of amphipods was recorded at the end of the experiment and the median lethal temperatures (LT<sub>50</sub>) at a salinity of 30 were determined as described in the next section.

To investigate salinity effects, the amphipods were exposed to 0, 2, 5, 8, 10, 20, 30, 40, 50, 55, 58, 60, 62 and 65 salinities at 25°C for 96 h. Salinity of the medium was adjusted from 30 to the experimental value at a rate of 2–5 h<sup>-1</sup>. The median lethal salinities (LS<sub>50</sub>) at 25°C were also determined as described below.

*Data analyses.* Results from the lethal tests were analysed by probit analysis using the computer software USEPA Probit Analysis program version 1.5. Probit transformation was applied to the cumulative mortality data. The values of 96-h LT<sub>50</sub> were estimated within both low (0–14°C) and high (30–35°C) temperature ranges, while the values of 96-h LS<sub>50</sub> were estimated within low (0–10) and high (50–65) salinity ranges. Data from adults and juveniles were compared using Student's *t*-test (Zar 1996). The computer softwares Sigmaplot version 2.03 and Sigmaplot 2000 were used.

#### *Growth of juveniles at different temperatures and salinities*

*Culture.* Ovigerous females were collected from the outdoor culture tanks. No more than two newly hatched juveniles were taken from each female for experiments. Ten juveniles were studied under each combination of temperature (15, 20 and 25°C) and salinity (10, 20, 30 and 40). Each juvenile was reared individually in a 100-ml beaker for any specific temperature–salinity combination. Temperature and salinity were adjusted from acclimated conditions at the rates of 2°C h<sup>-1</sup> and 2 h<sup>-1</sup>, respectively. Each juvenile was fed with a piece of krill (1–2 mm<sup>3</sup>) and algal thalli which had been immersed in artificial sea water of the respective combination of salinity and temperature for about an hour before the start of the experiment. The culture procedures were similar to those described in the previous section. Physical characteristics of the experimental media (temperature, salinity, pH and dissolved oxygen) were monitored every 2 days.

*Growth measurement.* Each juvenile was examined daily for moulting. Moulting was evidenced by the presence of the exuvium in the beaker. The day of exuvium appearance was regarded as the day of moulting. Body length (from rostrum to posterodistal end of urosomite 3 in a naturally curved posture) was measured 1 day after moulting. As the body length between the two sexes began to differ significantly at instar 7 (Tsoi 1999), growth study on juveniles was limited to the first six instars. To measure body length (BL), the

amphipod was placed on a glass slide and covered with a small sheet of thin plastic film. Each amphipod was examined for <2 min to minimize the effects of hypoxia and handling stress. The image of each amphipod was recorded using a compound microscope (Nikon model SE) and a colour camera set (Teli® CCD CS 5110), and the body length was measured to 0.01 mm with a video-based image analysing program (Quantimet 500C).

*Data analysis.* Statistical analyses including Student's *t*-test, two-factor analysis of variance (ANOVA) followed by Tukey test were performed using the computer software Sigmastat version 2.03.

## Results

### *Survival at different temperatures and salinities*

At a salinity of 30, >90% of adults and juveniles survived for 96 h between 6 and 28°C (Figure 1A). Survival was <90% when the temperature was <6°C or >28°C. No amphipod survived at 0 or 35°C for >24 h. The values of the low-range 96-h LT<sub>50</sub> differed significantly between adults and juveniles (Student's *t*-test; *P*=0.02), indicating that adults were more tolerant to low temperature than juveniles (Table I). No amphipod remained active after 96 h of exposure to 4 and 6°C, but sluggish animals became reactivated within 15 min after transfer to 25°C. All 'recovered' amphipods were still alive after 24 h of incubation at room temperature. There was no significant difference in the values of high-range 96-h LT<sub>50</sub> between adults and juveniles (*P*>0.5) (Table I).

In salinities ranging from 10 to 30, >90% of the amphipods survived for 96 h at 25°C (Figure 1B). Survival rate decreased at more extreme salinities. No amphipod could survive for >24 h and >48 h at salinities of 0 (distilled water) or 65, respectively. The values of 96-h LS<sub>50</sub> between adults and juveniles were not significantly different in either low (*P*=0.10) or high (*P*=0.49) salinity ranges.

### *Growth of juveniles at different temperatures and salinities*

Growth rate of juveniles expressed as increase in BL per day during the juvenile stage (instars 1–6) was calculated at different temperature–salinity combinations (Table II). Both factors affected growth rate significantly (two-factor ANOVA; *P*<0.001). Growth rate was highest at 25°C and a salinity of 20 (0.114±0.006 mm day<sup>-1</sup>) (two-factor ANOVA with temperature and salinity as major factors; *P*<0.001). Variations in either moult increment in BL or intermoult duration, or both, could affect the growth rate of juveniles. At a salinity of 20, juveniles reared at 25°C showed the highest percentage moult increment in BL among the temperatures studied and the deviation became significant at the transition from instar 3 to 4 (Tukey test after two-factor ANOVA with temperature and instar as major factors; *P*<0.05) (Figure 2A). At 25°C, juveniles reared at a salinity of 20 showed the greatest percentage moult increment in BL among the salinities studied and the deviation became significant at the transition from instar 3 to 4 (Tukey test after two-factor ANOVA with salinity and instar as major factors; *P*<0.05) (Figure 2B).

At a salinity of 20, intermoult duration of the juveniles reared at 15°C was the longest among the temperatures studied from instar 1 (Tukey test after two-factor ANOVA with temperature and instar as major factors; *P*<0.01) (Figure 3A). In contrast, the duration

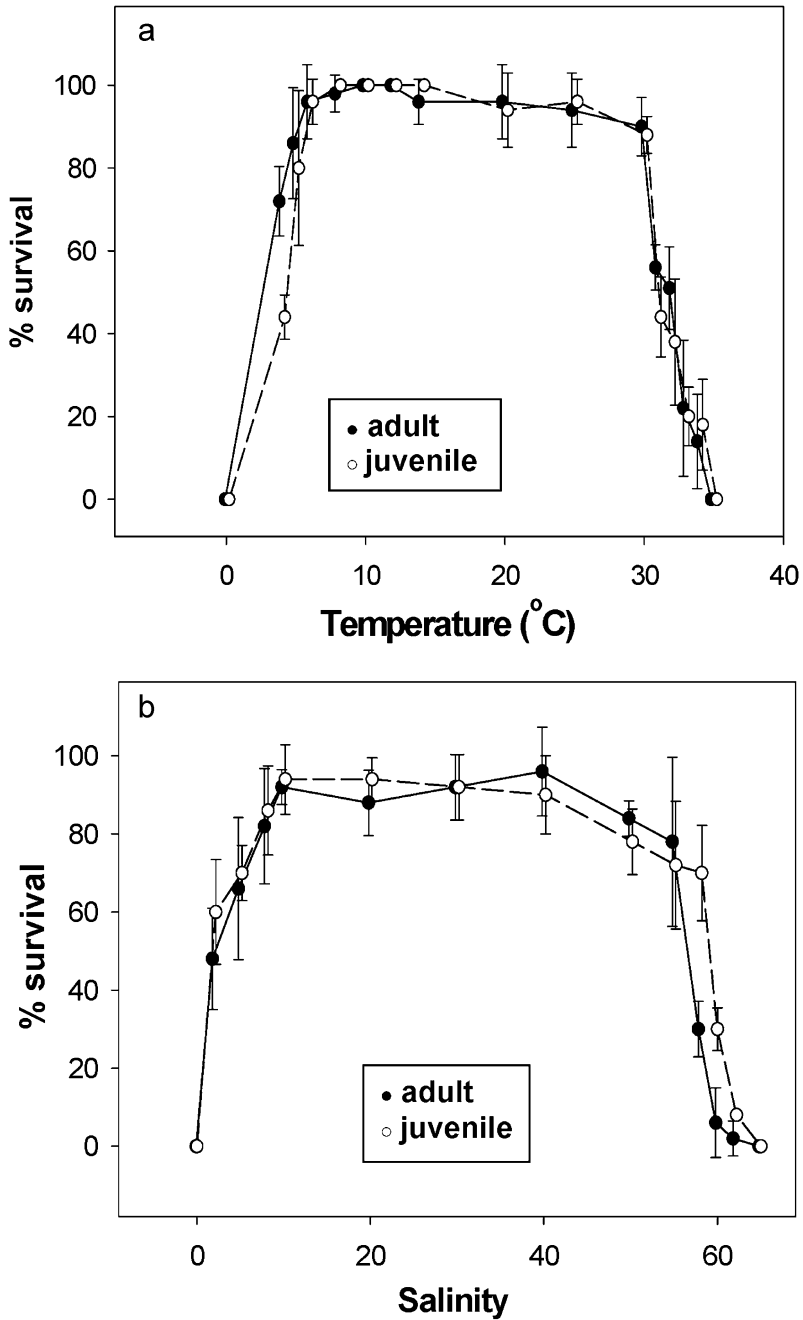


Figure 1. Survival of *Hyale crassicornis* adults and juveniles after 96 h of exposure to (a) different temperatures at a salinity of 30 and (b) different salinities at 25°C. Values are expressed as mean  $\pm$  SD of five replicate experiments, each of 10 individuals.

was the shortest at 25°C ( $P < 0.001$ ). However, no significant difference was observed in intermolt duration among the four salinities studied (two-factor ANOVA with salinity and instar as major factors;  $P = 0.06$ ) (Figure 3B).

Table I. Median lethal temperature and salinity (96 h) of *Hyale crassicornis* juveniles and adults.

	96-h LT <sub>50</sub> (°C)		96-h LS <sub>50</sub>	
	Low temperature	High temperature	Low salinity	High salinity
Adult	3.2 (2.6–3.6)*	31.7 (31.1–32.3)	2.4 (1.7–2.9)	55.5 (50.9–58.1)
Juvenile	4.2 (3.9–4.3)*	31.5 (29.7–32.5)	1.6 (0.9–2.2)	56.9 (42.1–62.4)

Values are expressed as mean and 95% confidence interval (in parentheses) of five replicate experiments, each of 10 individuals. \*Significant difference between adult and juvenile.

Table II. Body length (BL) of *Hyale crassicornis* juveniles at instar 6, and duration and growth rate of juveniles (instars 1–6) reared at different combinations of salinity and temperature.

Salinity		Temperature (°C)		
		15	20	25
10	BL (mm)	3.40 ± 0.15	3.16 ± 0.12	3.09 ± 0.06
	Duration (days)	38.5 ± 3.5	26.5 ± 3.6	26.9 ± 3.4
	Growth rate (mm day <sup>-1</sup> )	0.055 ± 0.005	0.055 ± 0.045	0.060 ± 0.003
20	BL (mm)	3.48 ± 0.15	3.65 ± 0.20	4.54 ± 0.25
	Duration (days)	33.9 ± 3.4	27.9 ± 4.3	25.3 ± 3.7
	Growth rate (mm day <sup>-1</sup> )	0.061 ± 0.004	0.080 ± 0.009	0.114 ± 0.006
30	BL (mm)	2.90 ± 0.16	3.89 ± 0.18	3.92 ± 0.18
	Duration (days)	33.4 ± 3.5	30.3 ± 3.6	29.1 ± 4.8
	Growth rate (mm day <sup>-1</sup> )	0.044 ± 0.005	0.081 ± 0.005	0.009 ± 0.008
40	BL (mm)	3.31 ± 0.17	2.57 ± 0.19	3.25 ± 0.19
	Duration (days)	37.6 ± 4.4	33.8 ± 4.7	29.2 ± 3.5
	Growth rate (mm day <sup>-1</sup> )	0.051 ± 0.005	0.067 ± 0.006	0.067 ± 0.001

Growth rate is expressed as increase of body length per day (mm day<sup>-1</sup>). Values are mean ± SD ( $n=10$ ).

In summary, the growth rate of juveniles was highest at 25°C and a salinity of 20 as a result of an increase in moult increment of BL and a shortening of intermoult duration. Temperature exerted significant effects in both moult increment and intermoult duration. However, salinity only exerted its effects on moult increment, not on intermoult duration.

## Discussion

### *Survival at different temperatures and salinities*

This study shows that, on average, 90% of *Hyale crassicornis* could survive for 4 days at 6–28°C. The species could not survive at 0 or 35°C. Another member of the same superfamily Talitroidea, the sub-Antarctic beach-hopper '*Orchestia scutigerula* Dana, 1853 exhibits a different range of temperature tolerance (Moore et al. 1995). The lethal temperatures of this species are < -4°C and > 28°C. Brown and Bert (1993) suggested that the difference in temperature tolerance of crustaceans may be the consequence of adaptation to different environmental conditions. '*Orchestia scutigerula* was found beneath supralittoral stones in sub-Antarctic regions where the environmental temperature could change dramatically (Moore et al. 1995). In Hong Kong, *H. crassicornis* is exposed to water temperatures ranging between 16 and 32°C. This species exhibits a higher tolerance to high temperature but lower tolerance to low temperature than '*Orchestia scutigerula*. The difference in



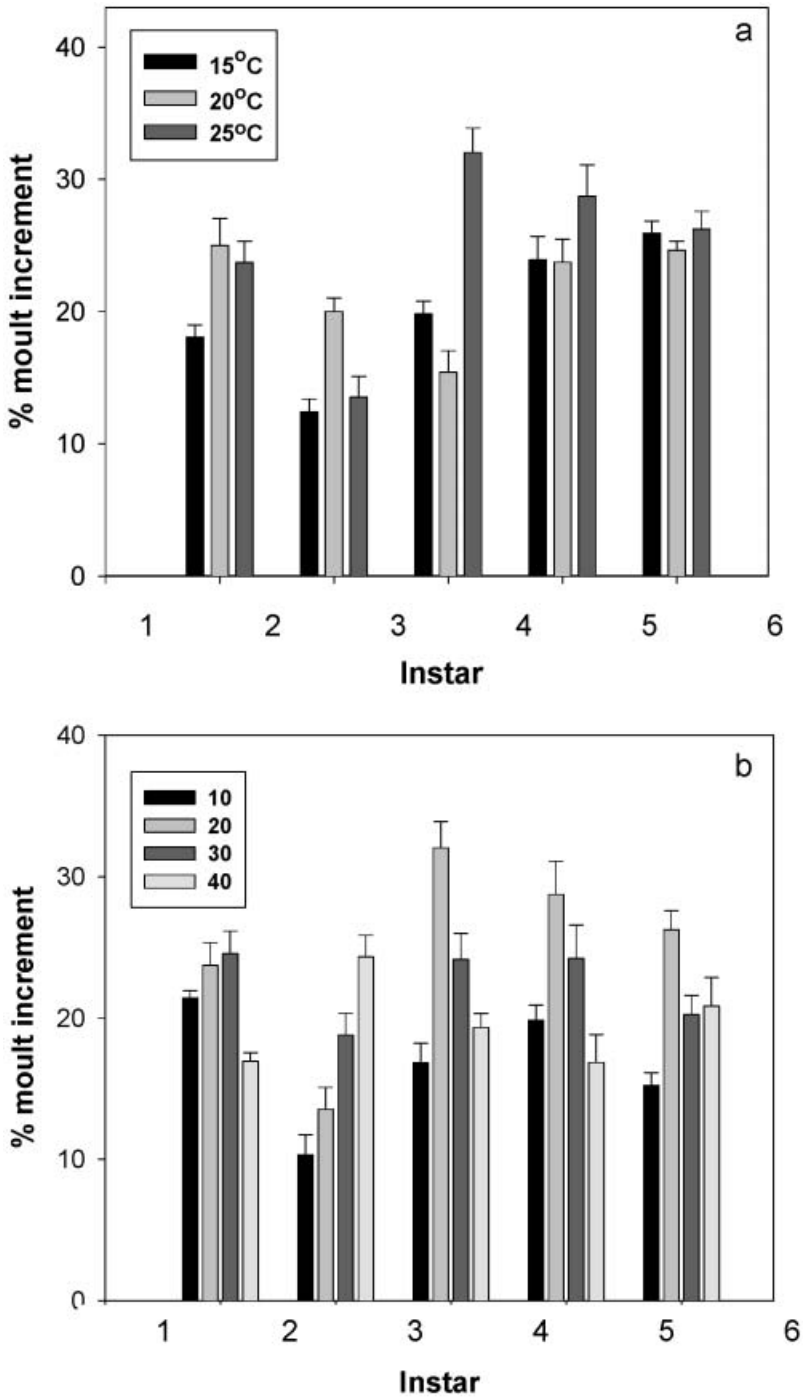


Figure 2. Mould increment expressed as percentage increase in body length at each instar from 1 to 6 (mean  $\pm$  SE,  $n=10$ ) of *Hyale crassicornis* juveniles reared at (a) different temperatures at a salinity of 20 and (b) different salinities at 25°C.

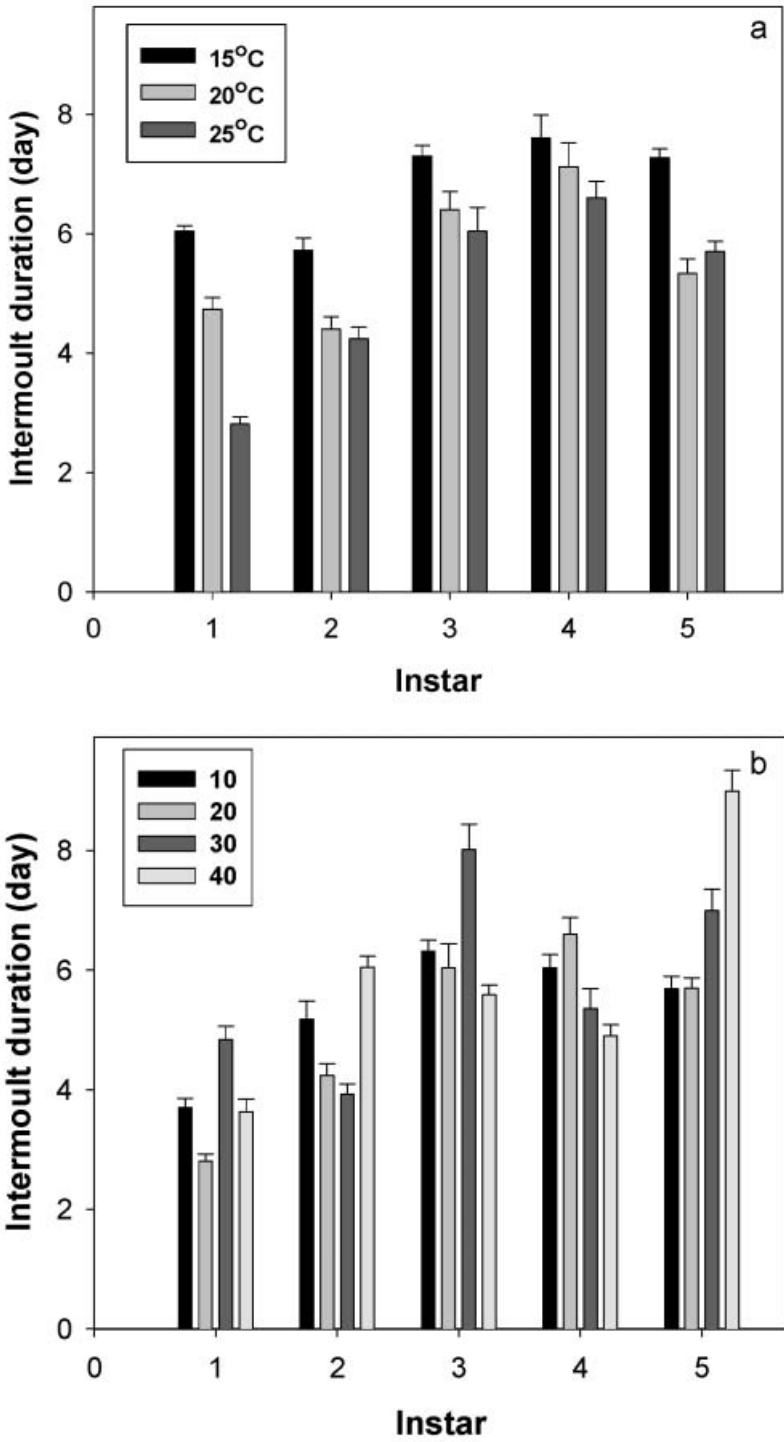


Figure 3. Intermolt duration (mean  $\pm$  SE,  $n=10$ ) of each instar from 1 to 6 in *Hyale crassicornis* juveniles reared at (a) different temperatures at a salinity of 20 and (b) different salinities at 25°C.

thermal tolerance between these species is apparently associated with habitats. Thermal tolerance can also be attenuated by salinity change and the presence of certain chemicals. For instance, soft-shell snow crab *Chionoecetes opilio* (Fabricius, 1788) is more susceptible to thermal stress at low ambient salinity (Hardy et al. 1994). Ammonia or nitrite exposure weakens the thermal tolerance of the post-larvae of the white shrimp *Penaeus setiferus* (Alcaraz et al. 1997). Thus the data obtained from this study (both the high and low temperature ranges) may not reflect the survival limits of *H. crassicornis* in the field because of the seasonal fluctuation of salinity (heavy rainfall in summer) and pollution. Further studies are required to investigate the interacting effects of these environmental factors on the survival of this species.

Many shore invertebrates can survive in habitats where abrupt changes in salinity take place (Kinne 1971). *Hyale crassicornis* is able to survive (>80%) in a wide range of salinities between 10 and 50. The 96-h LS<sub>50</sub> values of adults at high and low salinity ranges were 55.5 and 2.4, respectively. The corresponding values for juveniles were 56.9 and 1.6. These values are similar to those reported in other euryhaline crustaceans, such as the isopod *Sphaeroma serratum* (Fabricius, 1787). The high and low values of 96-h LS<sub>50</sub> in stage I juvenile *S. serratum* were 59 and 13, respectively (Charmantier and Charmantier-Daures 1994). The values of 21-day LS<sub>50</sub> in the blue crab *Callinectes similis* Williams, 1966 were 60.8 and 2.6 at high and low salinity ranges, respectively (Guerin and Stickle, 1997b). The high salinity tolerance of *H. crassicornis* is consistent with the results from studies on various members of the same superfamily Talitroidea. For instance, the euryhaline *Traskorchestia traskiana* (Stimpson, 1857) can tolerate salinities between 2.5 and 50 for at least a week at 10°C (Koch 1991). *Orchestia gammarellus* (Pallas, 1766) survives between 1 and 60 (Moore and Francis 1986), while *Traskorchestia chiliensis* (Milne-Edwards, 1840) survives within the range of 0.3–51 (Marsden 1980). Such tolerance is associated with their strong osmoregulatory capabilities. Spicer and Taylor (1987) reported that haemolymph sodium of *O. gammarellus* was actively regulated within a narrow range between 204 and 443 mmol kg<sup>-1</sup> when the amphipod was exposed to salinities of 5 (≈135 mmol kg<sup>-1</sup>) or 40 (≈1160 mmol kg<sup>-1</sup>).

#### *Growth of juveniles at different temperatures and salinities*

Temperature exerts a significant impact on the growth of crustaceans. The present study reveals that the growth rate of *H. crassicornis* is higher at 25°C than at 15°C and 20°C. Similar findings have been reported in other crustaceans. Penaeid shrimp juveniles grow faster at a higher temperature (Chen et al. 1995; Kumlu et al. 2000). The growth increment of *Penaeus vannamei* (Boone, 1931) is extremely sensitive to a moderate increase in temperature from 23 to 27°C (Wyban et al. 1995). Growth rate and moulting frequency of *Penaeus japonicus* Bate, 1888 are higher at 32 than 28°C (Hewitt and Duncan 2001).

Temperature also exerts effects on intermoult duration, which in turn affects the growth of crustaceans (Hartnoll 1982). Mean intermoult duration of juvenile *H. crassicornis* was extended from 5.08 days at 25°C to 6.79 days at 15°C. Such extension at low temperature has been frequently reported for other crustaceans. Thus, duration of larval instar in the stone crab *Menippe mercenaria* (Say, 1818) lengthened as temperature decreased from 30 to 25°C (Brown et al. 1992). Intermoult duration of *Penaeus merguensis* De Man, 1888 increased from 3 days at 35°C to 12 days at 15°C (Staples and Heales 1991).

Other than temperature, salinity is another critical factor exerting significant effects on crustacean growth. For instance, dry weight of the blue crab *Callinectes similis* juveniles

reared at a salinity of 5 was half of those reared at 10 (Guerin and Stickle 1997b). In this study, we found that the optimal salinity for growth of *H. crassicornis* juveniles is 20 at 25°C. The phenomenon can be explained by the physiological relationship between salinity and metabolism. A higher oxygen consumption rate may indicate a higher energy requirement for osmoregulation under osmotic stress, reducing energy available for growth (Einarson 1993). The fasting and feeding oxygen consumption of *P. vannamei* juveniles increases under low ambient salinity because more energy is diverted to maintain homeostasis (Rosas et al. 2001). The scope for growth in the blue crab *Callinectes similis* juveniles is the highest at a salinity of 35 (Guerin and Stickle 1997b). *Penaeus chinensis* exhibits the fastest growth rate at the isosmotic point of 16.5, suggesting that less energy is spent on osmoregulation at this salinity (Chen et al. 1992, 1996). Other than energy consumption, utilization of nutrients is also affected by salinity, leading to altered growth rate (Venkataramiah et al. 1972).

Any effects leading to either an increase in moult increment of body size or shortening in intermoult duration could result in a higher growth rate. Our study reveals that *H. crassicornis* juveniles reared at a salinity of 20 had the highest percentage moult increment in body length compared with those reared at 15 and 25. Yet salinity exerts little effect on intermoult duration of the juveniles. This phenomenon has also been reported in the banana shrimp *P. merguensis* (Staples and Heales 1991). Salinity affects growth of this shrimp through changes in the moult increment rather than intermoult duration. Insignificant effects of salinity on intermoult duration have been reported in juvenile *Callinectes sapidus* Rathbun, 1896 (Cadman and Weinstein 1988; Guerin and Stickle 1992), *Menippe mercenaria* (Brown et al. 1992) and *P. chinensis* (Chen et al. 1992). Yet some crustaceans exhibit prolonged developmental duration only under extreme salinity. Examples include *Rhithropanopeus harrisi* (Gould, 1841) post-larvae at salinities of 2.5 and 40 (Costlow et al. 1966) and *Armases miersii* (Rathbun, 1897) larvae and juveniles at salinities of 5 and 45–55 (Anger 1996). This is consistent with our observation that salinity has little influence on intermoult duration.

Environmental factors interact to produce physiological effects on marine invertebrates (Staples and Heales 1991; O'Brien 1994). These effects in turn affect growth rate and growth pattern of crustaceans (Hartnoll 2001). The highest growth rate of *H. crassicornis* juveniles was 0.11 mm day<sup>-1</sup> at 25°C and a salinity of 20, while the growth rate of animals reared at other temperature–salinity combinations ranged between 0.04 and 0.08 mm day<sup>-1</sup>. Such growth rates are comparable to those reported in other amphipods. For instance, the growth rates of *Hyale barbicornis* Hiwatari and Kajihara, 1981 juveniles at 24°C were 0.10 and 0.15 mm day<sup>-1</sup> in males and females, respectively (Hiwatari and Kajihara 1988). The optimal combination of conditions for growth of *H. crassicornis* juveniles was 25°C and a salinity of 20. The optimal temperature–salinity combination for growth is species-specific (Chen and Chen 1993; Kumlu et al. 2001). For example, the optimal culture conditions in juvenile or larval penaeid shrimps: *P. semisulcatus* De Haan, 1844, *P. esculentus* Haswell, 1879, *P. merguensis* and *P. chinensis* are 30°C and 30–35 salinity (Kumlu et al. 2000), 30°C and 30 salinity (O'Brien 1994), 28°C and 28 (Staples and Heales 1991) and 30°C and 20–30 salinity (Chen et al. 1996), respectively.

In summary, the growth pattern of *H. crassicornis* is controlled by both temperature and salinity. Change in moult increment of body size is driven by both temperature and salinity while intermoult duration appears to be influenced by temperature alone. Growth of *H. crassicornis* juveniles is optimal at 25°C and a salinity of 20. While these data from our laboratory experiments are valuable in the development of pollution bioassays, further

studies are required to understand the impact of temperature and salinity variations on natural populations of this amphipod.

### Acknowledgements

We express our sincere gratitude to X. Q. Ren (The Institute of Oceanology, The Chinese Academy of Sciences, Qingdao, China) for identification of the amphipod species. We thank P. G. Moore (University of Glasgow) and C. K. Wong (The Chinese University of Hong Kong) for their comments on the manuscript. Some results of this study constitute part of a thesis submitted by K. H. Tsoi as partial fulfilment of the requirement for the degree of Master of Philosophy, Division of Biology, The Chinese University of Hong Kong.

### References

- Alcaraz G, Chiappa-Carrara X, Vanegas C. 1997. Temperature tolerance of *Penaeus setiferus* postlarvae exposed to ammonia and nitrite. *Aquatic Toxicology* 39:345–353.
- Anger K. 1996. Salinity tolerance of the larvae and first juveniles of a semiterrestrial grapsid crab, *Armases miersii* (Rathbun). *Journal of Experimental Marine Biology and Ecology* 202:205–223.
- Barnard JL. 1974. Gamaridean Amphipoda of Australia Part II. *Smithsonian Contributions to Zoology* 139: 50–54.
- Brown SD, Bert TM. 1993. The effects of temperature and salinity on moulting and survival of *Menippe adina* and *M. mercenaria* (Crustacea, Decapoda) postsettlement juveniles. *Marine Ecology Progress Series* 99:41–49.
- Brown SD, Bert TM, Tweedale WA, Torres JJ, Lindberg WJ. 1992. The effects of temperature and salinity on survival and development of early life stage Florida stone crabs *Menippe mercenaria* (Say). *Journal of Experimental Marine Biology and Ecology* 157:115–136.
- Cadman LR, Weinstein MP. 1988. Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs *Callinectes sapidus* Rathbun. *Journal of Experimental Marine Biology and Ecology* 121:193–207.
- Charmantier G, Charmantier-Daures M. 1994. Ontogeny of osmoregulation and salinity tolerance in the isopod crustacean *Sphaeroma serratum*. *Marine Ecology Progress Series* 114:93–102.
- Chen CP, Chen BY. 1993. The effect of temperature–salinity combinations on survival and growth of juvenile *Patiriella pseudoexigua* (Echinodermata: Asteroidea). *Marine Biology* 115:119–122.
- Chen JC, Lin MN, Lin JL, Ting YY. 1992. Effect of salinity on growth of *Penaeus chinensis* juveniles. *Comparative Biochemistry and Physiology* 102A:343–346.
- Chen JC, Lin MN, Ting YY, Lin JN. 1995. Survival, haemolymph osmolality and tissue water of *Penaeus chinensis* juveniles acclimated to different salinity and temperature levels. *Comparative Biochemistry and Physiology* 110A:253–258.
- Chen JC, Lin JN, Chen CT, Lin MN. 1996. Survival, growth and intermoult period of juvenile *Penaeus chinensis* (Osbeck) reared at different combinations of salinity and temperature. *Journal of Experimental Marine Biology and Ecology* 204:169–178.
- Costlow JD, Bookhout CG, Monroe RJ. 1966. Studies on the larval development of the crab, *Rhithropanopeus harrisi* (Gould). 1. The effect of salinity and temperature on larval development. *Physiological Zoology* 39:81–100.
- Einarson S. 1993. Effects of temperature, seawater osmolality and season on oxygen consumption and osmoregulation of the amphipod *Gammarus oceanicus*. *Marine Biology* 117:599–606.
- Guerin JL, Stickle WB. 1992. Effects of salinity gradients on the tolerance and bioenergetics of juvenile blue crabs (*Callinectes sapidus*) from waters of different environmental salinities. *Marine Biology* 114:391–396.
- Guerin JL, Stickle WB. 1997a. A comparative study of two sympatric species within the genus *Callinectes*: Osmoregulation, long-term acclimation to salinity on growth and moulting. *Journal of Experimental Marine Biology and Ecology* 218:165–186.
- Guerin JL, Stickle WB. 1997b. Effect of salinity on survival and bioenergetics of juvenile lesser blue crabs, *Callinectes similis*. *Marine Biology* 129:63–69.
- Hardy D, Munro J, Dutil JD. 1994. Temperature and salinity tolerance of the soft-shell and hard-shell male snow crab, *Chionoecetes opilio*. *Aquaculture* 122:249–265.

- Hartnoll RG. 1982. Growth. In: Abele LG, editor. *The Biology of Crustacea*, Vol. 2. New York: Academic Press. p 111–196.
- Hartnoll RG. 2001. Growth in Crustacea: Twenty years on. *Hydrobiologia* 449:111–122.
- Hewitt DR, Duncan PF. 2001. Effect of high water temperature on the survival, moulting and food consumption of *Penaeus (Marsupenaeus) japonicus* (Bate 1888). *Aquaculture Research* 32:305–313.
- Hiwatari T, Kajihara T. 1988. Experimental studies on the growth and breeding of *Hyale barbicornis* (Amphipoda, Crustacea) at different temperatures. *Nippon Suisan Gakkaishi* 54:39–43.
- Jiang JX, Zhou QL. 1982. A preliminary survey of the rocky intertidal communities along Tolo Harbour, Hong Kong. In: Morton B, Tseng CK, editors. *Proceedings of the Second International Marine Biological Workshop: The Marine Flora and Fauna of the Hong Kong and Southern China*, Hong Kong, 1980. Hong Kong: Hong Kong University Press. p 673–686.
- Kinne O. 1970. Temperature. In: Kinne O, editor. *Marine Ecology*. Vol. 1. Part 1. London: Wiley-Interscience. p 321–514.
- Kinne O. 1971. Salinity. In: Kinne O, editor. *Marine Ecology*. Vol. 1. Part 2. London: Wiley-Interscience. p 683–1244.
- Koch H. 1991. Salinity tolerance and osmoregulation of *Traskorchestia traskiana* (Stimpson 1857) (Amphipoda, Talitridae). *Crustaceana* 61:21–37.
- Kumlu M, Eroldogan OT, Aktas M. 2000. Effects of temperature and salinity on larval growth, survival and development of *Penaeus semisulcatus*. *Aquaculture* 188:167–173.
- Kumlu M, Eroldogan OT, Aktas M, Saglamtimur B. 2001. Larval growth, survival and development of *Metapenaeus monoceros* (Fabricius) cultured in different salinities. *Aquaculture Research* 32:81–86.
- Marsden I. 1980. Effects of constant and cyclic temperatures on salinity tolerance of the estuarine sandhopper *Orchestia chilensis*. *Marine Biology* 59:211–218.
- Moore PG. 1986. Preliminary notes on a collection of Amphipoda from Hong Kong. In: Morton B, editor. *Proceedings of the Second International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China*, Hong Kong, 1986. Hong Kong: Hong Kong University Press. p 503–513.
- Moore PG, Francis CH. 1986. Environmental tolerances of the beach-hopper *Orchestia gammarellus* (Pallas) (Crustacea: Amphipoda). *Marine Environmental Research* 19:115–129.
- Moore PG, Macalister HE, Taylor AC. 1995. The environmental tolerances and behavioural ecology of the sub-Antarctic beach-hopper '*Orchestia scutigera*' Dana (Crustacea: Amphipoda) from Husvik, South Georgia. *Journal of Experimental Marine Biology and Ecology* 189:159–182.
- O'Brien CJ. 1994. The effects of temperature and salinity on growth and survival of juvenile tiger prawn *Penaeus esculentus*. *Journal of Experimental Marine Biology and Ecology* 183:133–145.
- Rosas C, Ramirez P. 1993. Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* exposed to hard and soft water. *Bulletin of Environmental Contamination and Toxicology* 51:568–574.
- Rosas C, Lopez N, Mercado P, Martinez E. 2001. Effect of salinity acclimation on oxygen consumption of juveniles of the white shrimp *Litopenaeus vannamei*. *Journal of Crustacean Biology* 21:912–922.
- Spicer JJ, Taylor AC. 1987. Ionic regulation and salinity related changes in haemolymph protein in the semi-terrestrial beach-flea *Orchestia gammarellus* Pallas (Crustacea: Amphipoda). *Comparative Biochemistry and Physiology* 88A:243–246.
- Staples DJ, Heales DS. 1991. Temperature and salinity optima for growth and survival of juvenile banana prawn *Penaeus merguensis*. *Journal of Experimental Marine Biology and Ecology* 154:251–274.
- Thomas RE, Rice SD. 1992. Salinity tolerance of adult and juvenile red king crab *Paralithodes camtschatica*. *Comparative Biochemistry and Physiology* 103A:433–437.
- Tsoi KH. 1999. *Biology of the amphipod Hyale sp. (Gammaridea, Hyalidae)*. MPhil thesis, The Chinese University of Hong Kong, Hong Kong.
- Venkataramiah A, Lakshmi GJ, Gunter G. 1972. The effect of salinity and feeding levels on the growth rate and food conversion efficiency of the shrimp *Penaeus aztecus*. *Proceedings of the World Mariculture Society* 3:267–283.
- Wyban J, Walsh WA, Godin DM. 1995. Temperature effects on growth, feeding rate and feed conversion of the Pacific white shrimp (*Penaeus vannamei*). *Aquaculture* 138:267–279.
- Zanders IP, Rojas WE. 1992. Cadmium accumulation, LC<sub>50</sub> and oxygen consumption in the tropical marine amphipod *Elasmopus rapax*. *Marine Biology* 113:409–413.
- Zar JH. 1996. *Biostatistical Analysis*, 3rd edn. London: Prentice Hall.