# Effect of temperature stress on the survival of juvenile Chinese mitten crab (*Eriocheir sinensis*)

Peng J.<sup>1,2</sup>; Zhao Y.L.<sup>1,2</sup>\*; Xu Z.G.<sup>2,3</sup>\*; Liu B.Q.<sup>2</sup>; Duan C.C.<sup>1,2</sup>; Tang Y.C.<sup>1</sup>

Received: January 2017 Accepted: May 2017

### **Abstract**

Eriocheir sinensis, which is an important aquaculture species, belongs to the class Crustacea. To discuss the temperature tolerance of E. sinensis, the survival rates of juvenile crabs of E. sinensis were determined in this paper using a series of temperature settings (normal temperature, 25°C, 30°C, 32°C, 34°C, 35°C, 36°C, 38°C, 40°C). The results indicated that except the normal temperature level, mortality rate almost reached 100% at other temperatures. The time of death of all crabs at  $30^{\circ}$ C,  $35^{\circ}$ C, and  $40^{\circ}$ C was different. All the crabs died in only 10 minutes at 40°C, while they died after 3 days and 7 days at 35 °C and 30°C, respectively. In addition to normal temperature conditions, minimum survival time of the juvenile crabs of E. sinensis at other temperature condition was no more than 24 h. Before the 8th day, the death rate at 30°C and normal temperature was different, change of turning slope for concentration of NH<sub>3</sub>-N and TN was contrary. Under normal temperature, the behavior of abdomen extension was not observed in juvenile crabs but the percentage time of abdomen extension was relatively long at 25°C. This research studied the influence of temperature stress on the survival of juvenile crabs of E. sinensis to provide information reference for the production and transportation of juvenile crab of *E. sinensis*.

**Keywords**: *Eriocheir sinensis*, Temperature stress, Survival, Behavior response

<sup>1-</sup> Key Laboratory of Forestry Remote Sensing Based Big Data & Ecological Security for Hunan Province, Central South University of Forestry and Technology, Changsha 410004, China

<sup>2-</sup> Engineering Research Center for Internet of Animals, Changsha 410128, China

<sup>3-</sup> Hunan Urban and Rural Ecological Planning and Restoration Engineering Research Center, Hunan City University, Yiyang 413000, China

<sup>\*</sup>Corresponding author's Email: zyl8291290@163.com; rssq198677@163.com

# Introduction

The Chinese mitten crab (Eriocheir sinensis) is considered to be one of the specific aquaculture species in China, which belongs to Crustacea, Decapoda, Crapsida, Eriocheir (Pan. 2002). Normally Chinese mitten crab were cultured for two years, in the first year it is cultured from crab larvae to button size, and in the other year it is cultured to market size in ponds, reservoirs or other waters fields. So the juvenile crabs of E. sinensis are also known as buttony crab. Chinese mitten crabs can survive in various environments, such as estuarine waters, freshwater lakes and ponds. In addition to China, the Chinese mitten crab is also distributed in Europe and the Americas (Zou and Si-Fa, 2002). Chinese mitten crabs are widely distributed in the Yangtze River, Liaohe, Oujiang and other waters in China, of which Yangtze River is the most excellent quality. Due to its high nutritional value and market demand, Chinese mitten crab has increasingly promising commercial become a species. The aquaculture industry has been rapidly developing in many parts with Chinese mitten crab aquaculture as a pillar industry of aquaculture (Wang et al., 2016).

Average water temperature in the middle and lower Yangtze River is 31-35°C in summer and 0-4°C in winter. Crab grow from early March to early November, for up to about 240 days. This temperature range is very suitable for the growth of Chinese mitten crabs (Zhang, 2000). With the global climate change, extreme weather is becoming more and more frequent. To understand

the survival mechanism of economic species under extreme weather, such as temperature, is particularly important. is one of the most Temperature important environmental factors affecting crabs, which can affect neuromuscular activity, respiration, blood circulation and lipid metabolism and other physiological activities (Aardt, 1993). The relationship between North America dungeness crab (Cancer magister) (Kondzela and Shirley, 1993; Sulkin and Mckeen, 1996), Red king crab (Kamchatka cancer) in the North Pacific (Shirley and Shirley 1989; and Onoda Kittaka 2002). North American blue crab (Callinectes sapidus) (Leffler, 1972; Fisher, 1999), Mud crab (Scylla serrata) (Hamasaki, 2003; Ruscoe et al., 2004), Distant sea crab (Portunus pelagicus) (Bryars and Havenhand, 2006) and temperature has been reported in a large number of literature. While, at present there is little research on temperature tolerance of Chinese mitten crab, (Bo Huang et al., 2001) focused on the effects of temperature on the E. sinensis larval growth and development. The results suggested that the survival rate increases with temperature.

In order to know more details on the biology of Chinese mitten crab and provide references for aquaculture to ensure the sustainable development of Chinese mitten crab industry, the juvenile crab was employed as the research object to study the impact of high temperature stress on its survival.

#### Materials and methods

254 juvenile crabs of E. sinensis, with

an average weight of 6-10 g, were captured from Dongting Lake region in China, where the crab culture was common and the crab was the main economic resource. Sampling was done in April, when water temperature in Dongting Lake is 15-23 °C. Normal body color, lively and healthy individuals were chosen and reared in freshwater lake (112.37°E, 29.07°N) to adapt to laboratory conditions.

2 weeks later, 200 juvenile crabs of E. sinensis were divided randomly into five groups (n=40 for each group, half male and half female), and transferred to five water tanks (80 cm×58 cm×40 for rearing. The following cm) temperatures were tested: 25°C, 30°C, 35°C, 40°C, normal temperature (<25°C) as the control group. Weight, carapace length, carapace width and height were measured for each crab before experiment (Montu et al., Pebbles, at a diameter of 2 cm, were placed at the bottom of the tanks serving as a crab refuge. The depth of the water was set at 30 cm, which was accordance with field culture environment. 5 g food was fed at 22:00 every day during the experiment. At the same time, an oxygen pump worked 8 hours every day to supply dissolved oxygen. Water temperature day normal measured every for temperature level and dead crabs were also recorded for all levels. At the same time, pH, ammonia nitrogen (NH<sub>3</sub>-N), nitrogen (TN) and total total phosphorus (TP) were also measured every three days.

In order to determine the threshold of

juvenile crabs of E. sinensis temperature precisely, an experiment with fewer intervals of temperature was designed. Glass aquaria (44 cm×28 cm ×28cm) with paving pebbles at the bottom and 24 cm of water column was used. The following temperature were tested: normal temperature, 25°C, 30°C, 32°C, 34°C, 35°C, 36°C, 38°C, 40°C. Three female crabs and three male crabs were reared in each temperature level. Death time of every crab was recorded for all the levels. Besides the death time, behavior response temperature was explored. The behavior of the juvenile crabs of E. sinensis different temperatures recorded with a Panasonic video camera (HDC-HS900) after 5 min for adaption. Behavioral indicators, locomotor activity, movement of mouthparts, cleaning of antennae, antennule retraction. flicking of antennae. percentage time of abdomen, eyestalk extension movement, and percentage time of closure behavior were distinguished (McGaw and McMahon., 1999). The behavior number sustained time of above behaviors were counted from the video. Because the living time was different, statistic was only carried out 1 min.

Temperature control device (Kedibo WK-SM3) was used in the experient to ensure the temperatures were as expected. Dissolved oxygen was measured with a portable dissolved oxygen device (Shanghai Leici JPB-607A). pH was measured with a portable pH device (Shanghai Leici PHS-3E). NH<sub>3</sub>-N, TN, TP were checked by standard method (Wei *et al.*, 2008)

An independent sample test was employed to analyze the role of sex and temperature in the survival process. Temperature control study using model behavior analysis.

#### Result

Morphology of juvenile crabs of Eriocheir sinensis

The morphological indexes of all experimental crabs were counted. The mean body weights of the crabs were measured to be  $8.543\pm2.555$  g for females and  $9.304\pm2.977$  g for males, the difference was significant (p<0.05). The average carapace length of female

crabs was  $2.409\pm0.270$  cm, the average carapace width of female crabs was  $2.617\pm0.284$  cm, and the average height at withers of female crabs was  $1.262\pm0.144$  cm; the average carapace length of male crabs was  $2.465\pm0.265$  cm, the average carapace width of male crabs was  $2.617\pm0.284$  cm, and the average height at withers of male crabs was  $1.269\pm0.162$  cm. There were no significant differences in mean carapace length, width and height between the females and the males (p>0.05). (Table 1).

Table 1: Morphology of juvenile of *Eriocheir sinensis*.

	Carapace length(cm) Mean±SD	Carapace width(cm) Mean±SD	Carapace height(cm) Mean±SD	Weight(g) Mean±SD
Females	2.409±0.270	2.617±0.284	1.262±0.144	8.543±2.555
Males	$2.465 \pm 0.265$	$2.628 \pm 0.291$	$1.269 \pm 0.162$	$9.304\pm2.977$
T-test	p > 0.05	p > 0.05	p > 0.05	p<0.05*

<sup>\*</sup> indicates significant difference (p<0.05).

Mortality rates of the juvenile crabs of E. sinensis at different temperatures Normal temperature fluctuated between 20°C ~ 25°C during the experiental period and was lower than the lowest temperature level, 25°C (Fig. Combined with the control temperature level. there was successive temperature gradient to explore relationship between survival and temperature of juvenile crabs of E. sinensis. With the increase temperature, from normal temperature, to 25°C, 30°C, 35°C and 40°C, mortality rate of crabs increased (Fig. 2). Except the normal temperature level, mortality rate almost reached 100% for other temperatures. Time of death of all crabs at 30°C, 35°C, 40°C was different.

At 40°C all crabs died in only 10 minutes, while they died in 3 days and 7 days at 35 °C and 30°C, respectively. There was an obvious tendency that high temperature meant the crabs would die in a shorter time. In accordance with the above tendency, mortality rate of crab reached 92.5% under 25°C on the 16th day. When all the crabs almost died for all control temperature levels, 50% of crabs in the normal temperature level, survived. Besides the mortality rate, there was also a huge difference in the death process. The death happened in such a short time that the mortality rate suddenly rose and reached 100% for the high temperature level, such as 30 °C or higher temperature. The crabs died gradually at temperature of 25°C and normal temperature level. Basing on the above analysis, temperature played an important role in the development of juvenile crabs of *E*.

sinensis. 25°C may be the threshold temperature for juvenile crabs of *E. sinensis*.

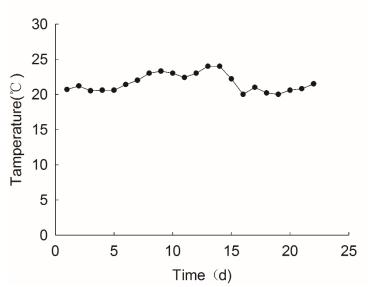


Figure 1: Fluctuations of normal temperature during the experience.

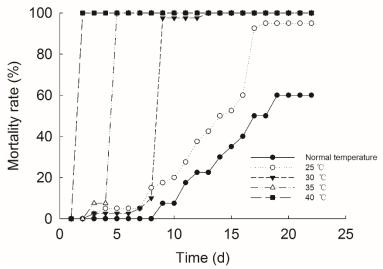


Figure 2: Mortality rate of juvenile of Eriocheir sinensis under different temperatures.

Survival time of the juvenile crabs of E. sinensis at different temperatures

There was a more direct evidence to show that at higher temperature, survival time was shorter. In addition to normal temperature condition, minimum survival time of the juvenile crabs of *E. sinensis* at other temperature conditions were no more than 24 h.

Maximum survival time of the juvenile of Ε. sinensis at normal temperature, 25°C, 30°C, 32°C, 34°C, 35°C, 36°C, 38°C, 40°C were 555 h, 423 h, 170.50 h, 168 h, 0.21h, 75h, 36h, 0.3h, 0.1h, respectively. Mean survival time were 394.50±130.60 h, 281.44±103.41 163.34±26.96 h, 84.28±91.71 h,  $3.86 \pm 4.71$ h,

 $72.05\pm13.18$  h,  $23.67\pm6.08$  h,  $0.09\pm0.10$  h,  $0.08\pm0.03$  h, respectively at the series of temperature gradient. Although there was a peak at 35°C, 36°C, the tendency

would not be changed. The tolerance of individuals was variable and the less test-crabs led to the result.

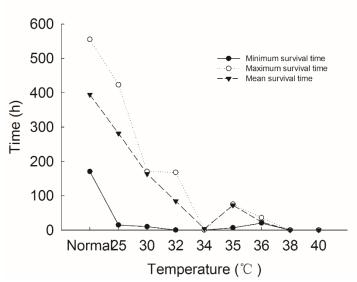


Figure 3: Survival time of juvenile of Eriocheir sinensis at different temperatures.

Change of water quality factors Because crabs died in short time at temperatures of 35°C and 40°C, only change of water quality at normal temperature, 25°C (threshold temperature) and 30°C are shown (Fig. 3). The concentration of NH<sub>3</sub>-N for the above temperature levels increased, although the gradient for different levels were variable (Fig. 4A). The regular pattern of concentration of TN was different from NH<sub>3</sub>-N. For the first four days of the experiment, the concentration of TN increased quickly and reached about 6 mg L<sup>-1</sup>, after which the concentration of TN fluctuated at 0.6 mg L<sup>-1</sup> (Fig. 4B). pH of water was alkalescence and ranged from 7.15 to 7.62 (Fig. 4C). Similar concentration of NH<sub>3</sub>-N, concentration of TP was also growing and gradient of normal temperature, 25°C and 30°C was similar (Fig. 4D).

Combined with the mortality rate of different temperature levels, the 8<sup>th</sup> day was an important node for 30°C because all crabs died and number of dead crabs was more than the other days. There was no jumping point for normal temperature and 25°C. Focusing on the change of water quality, especially the node. mechanism might explored. TP should not be the key factor to affect crab survival because there were no signification differences for different temperature levels. A common feature for NH3-N and TN have been that gotten, the concentrations of both at 30°C were higher than normal temperature and 25°C level. After 100% death, the concentration of NH<sub>3</sub>-N and TN at 30°C decreased. A steep increase of pH also revealed the clue, that there might be a close relationship between both NH<sub>3</sub>-N TN and crab survival.

concentrations of NH<sub>3</sub>-N and TN were not the highest nor the lowest, so there was no threshold value for Chinese mitten crab, but there was accumulation effect. Before the 8<sup>th</sup> day, the death rate at 30°C and normal temperature were different, change of turning slopes for concentrations of NH<sub>3</sub>-N and TN were contrary. The concentration of NH<sub>3</sub>-N and TN at 30°C rose first and then

declined. The concentration of NH<sub>3</sub>-N and TN at normal temperature always rose, but the gradient was different. No matter the death rate of crabs or concentrations of NH<sub>3</sub>-N and TN at 25°C was intergrade. Basing on the above analysis, change in concentration of NH<sub>3</sub>-N and TN might affect survival of the juvenile crabs of *E. sinensis*.

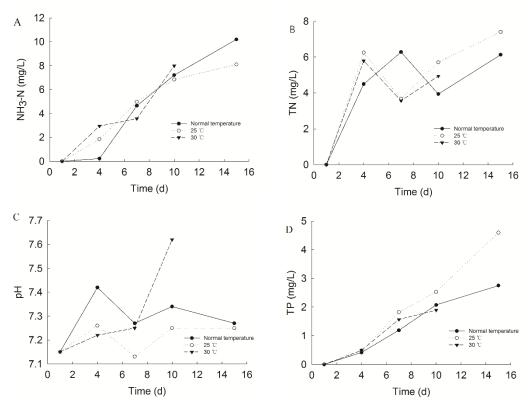


Figure 4: Water quality factor changes at different temperatures.

Behavioral responses to temperature change

The *E. sinensis* died quickly in conditions when temperature were over 25°C, so this paper only collects the statistics of behavior activities of *E. sinensis* under normal temperature or below 25°C (Table 2). No matter under normal temperature or below 25°C, there were no significant differences between the behaviors of female and

male crabs (p>0.05). The movement of mouth parts and flicking of antennae were the two main behaviors of juvenile crabs under two temperature gradients. Under different temperatures, there was no significant difference between the frequency of movement of mouth parts of female and male crabs (p>0.05); there was no significant difference between the frequencies of flicking of antennae for female crabs under

different temperatures. However, the frequency of flicking of antennae for male crabs was 100.67±2.52 under normal temperature and it 77.33±2.08 at 25°C. The frequency of flicking of antennae under normal temperature was significantly higher than that at 25°C (p < 0.01). Under normal temperature, the behavior of abdomen extension was not observed in juvenile crabs but the percentage time of abdomen extension was relatively long at 25°C. The percentage time of abdomen extension was 27.67±6.81 seconds within one minute for female

crabs and it was 41.33±9.87 seconds within one minute for male crabs. Significant differences could observed in terms of the percentage time of abdomen extension under two temperature conditions between female crabs and male crabs (p < 0.05). The frequency of locomotor activity. cleaning of antennae, antennule retraction and eyestalk movement was low and the difference was not obvious under two temperature gradients (p >0.05). Closure reaction was observed during the observation.

Table 2: Behavioral comparison between Eriocheir sinensis under different temperature.

		Normal temperature	25°C	p
Logomotor activity(n)	Female	1.00±1.00	1.67±0.58	p>0.05
Locomotor activity(n)	Male	3.33±1.53	1.33±2.31	p > 0.05
Movement of mouth ports(n)	Female	117±11.53	$103.00\pm20.95$	p > 0.05
Movement of mouth parts(n)	Male	81.33±19.09	94.00±14.18	p > 0.05
Cleaning of entennes (entenny local)	Female	$1.33\pm0.58$	$1.33\pm0.58$	p > 0.05
Cleaning of antennae/antennules(n)	Male	$3.67\pm2.08$	$0.67 \pm 0.58$	p > 0.05
Antannula naturation(n)	Female	$2.33\pm0.58$	1.67±1.53	p > 0.05
Antennule retraction(n)	Male	$2.00\pm2.00$	$2.67 \pm 0.58$	p > 0.05
Eliabina of automose(a)	Female	113±18.74	$84.33 \pm 14.3$	p > 0.05
Flicking of antennae(s)	Male	$100.67 \pm 2.52$	$77.33\pm2.08$	<i>p</i> <0.01**
Descente as time of chaleman automaion(c)	Female	0	$27.67 \pm 6.81$	<i>p</i> <0.05*
Percentage time of abdomen extension(s)	Male	0	$41.33\pm9.87$	<i>p</i> <0.05*
F	Female	$1.00\pm1.00$	1.33±1.53	p > 0.05
Eyestalk movement(n)	Male	$2.67 \pm 0.58$	1.33±1.16	p > 0.05
Demonstrate time of alcours helperion(a)	Female	0	0	
Percentage time of closure behavior(s)	Male	0	0	

<sup>\*\*</sup> represents highly significant difference; \* represents significant difference

## Discussion

The range between 20 to 25°C might be the suitable temperature for the growth of juvenile crabs of *E. sinensis*, which conformed to the temperature of the season in which large number of juvenile crabs of *E. sinensis* appear. If

the water temperature is over  $30^{\circ}$ C, it may lead to the death of juvenile crabs, which should be noted in artificial breeding practices. From existing reports of larval cultivation of *E. sinensis*, the most suitable cultivation temperature in the experiment of Chang

and Sang (1995) is 25°C. The appearance of juvenile crabs in Yangtze River Delta region was between April 15<sup>th</sup> to May 15<sup>th</sup> and the range of water temperature was between 20 to 25°C (Zhang 2002), which was roughly consistent with the results of this experiment.

The optimal survival temperature required by the E. sinensis at different growth periods is different. In the breeding season, the temperature range was 10°C to 20°C (Herrgesell et al., 1983). The survival rate of megalopa larva was the highest between 12 to 18°C and megalopa larva has relatively strong tolerance to low temperature. Afterwards. the optimal survival temperature gradually rises with the growth of larva (Anger, 1991). The optimal culture condition for adult E. sinensis was that the pH value was 6.8 and the water temperature was 28°C (Hong et al., 2013). This conforms to the real situation where water temperature at the beginning of the breeding peak of E. sinensis is low but gradually rises with the progress of time.

The temperature required during the shelling period of E. sinensis was relatively low. Although the mechanism in this aspect remains to be further investigated, the situation in and cultivation experiments indicates the shelling of larva of E. sinensis often occurs late at night or early in the morning when the water temperature was low, which reflects the choice of low temperature of larva of E. sinensis.

Alkaline pH was the suitable

environment for the growth of E. sinensis and the optimal range was 7.0 to 9.1. The respiratory activity of crustacean will be changed no matter whether it was lower of higher than this range. The ability to absorb oxygen from outside through gills will be influenced, thus affecting the oxygen consumption rate (Lin et al., 2000). The pH change during the course of this experiment was within the appropriate range and thus the pH change was not the primary cause of the death of crabs in this experiment. Although the TP concentration during the course of this experiment was higher than normal aquatic water, the change node of TP concentration was not consistent with the death time pf crabs. Therefore, the high TP concentration was also not the primary cause of the death of crabs in this experiment. No fresh water was poured during the course of this experiment, so the excreta of E. sinensis and the residue of feed led to the increase of ammonia concentration in the water. The increase of ammonia stress concentration and the extension of stress time led to the damage of nonspecific immune defense system of E. sinensis, thus accelerating the death of E. sinensis (Wang et al., 2006; Hong et al., 2007; Huang et al., 2006). However, the initial conditions in this experiment were consistent except the temperature, the increase of ammonia concentration was the possible cause but not the primary cause of the death acceleration of E. sinensis. Hong-Zhu Wang proposed that TN concentration is negatively correlated with crab yield in studying the stocking model of E.

sinensis in Yangtze River basin (Wang et al., 2006), which is consistent with the views of this paper.

In conclusion, temperature exerted great influence on the survival of juvenile crabs of E. sinensis. Obviously, temperature needs to be comprehensively considered in the production practice. Meanwhile, should attach great significance to water quality monitoring and make adjustments to abnormal conditions. To guarantee high survival rate of juvenile crabs of E. sinensis in breeding, transportation and other activities, the temperature should be controlled no higher than 30°C.

# Acknowledgments

The authors greatly appreciate Lei and Huimin HUANG **FENG** assistance with the field investigation. The authors also greatly appreciate **ZHANG** Oing who provided experiment samples. This research was by the supported National Research and Development Program of China (2014BAC09B03), International Science and Technology Cooperation Program of China (2015DFA90450), and Key Technology R&D Program of Hunan Province (2016TP1014).

#### References

Aardt, W.J.V., 1993. The influence of temperature on the haemocyanin function and oxygen uptake of the freshwater crab *Potamonautes warreni calman*. *Comparative Biochemistry and Physiology Part A Physiology*, 106, 31-35.

Anger, K., 1991. Effects of temperature

and salinity on the larval development of the Chinese mitten crab *Eriocheir Sinensis* (decapoda, grapsidae). *Marine Ecology Progress Series*, 72, 103-110.

**Bo Huang, H., Nan-shan, D. and Wei, L., 2001.** Effects of temperature and Ca<sup>2+</sup> on the larval development of the decapoda crustacean: *Eriocheir sinensis. Chinese Journal of Oceanology and Limnology*, 19, 228-232.

Bryars, S.R. and Havenhand, J.N., 2006. **Effects** of constant and varying temperatures on the development of blue swimmer crab (Portunus pelagicus) larvae: Laboratory observations and field predictions for temperate coastal waters. Journal of Experimental Marine Biology and Ecology, 329, 218-229.

**Fisher, M.R., 1999.** Effect of temperature and salinity on size at maturity of female blue crabs. *Transactions of the American Fisheries Society,* 128, 499-506.

Hamasaki, K., 2003. Effects of temperature on the egg incubation period, survival and developmental period of larvae of the mud crab *Scylla serrata* (Forskål) (Brachyura: Portunidae) reared in the laboratory. *Aquaculture*, 219, 561-572.

Herrgesell, P.L., Schaffter, R.G. and Larsen, C.J., 1983. Effects of freshwater outflow on San Francisco Bay biological resources. Interagency Ecological Study Program for the Sacramento—San Joaquin Estuary, Technical Report No. 7. July

- Hong, M.L., Chen, L.Q., Gu, S.Z., Liu, C., Long, Z.Q. and Zhang, W., **2007.** Effects of ammonia exposure immunity indicators haemolymph and histological structure hepatopancreas of Chinese mitten crab (Eriocheir **Journal** of sinensis). *Fishery* Sciences of China, 14, 412-418.
- Hong, Y., Yang, X., Cheng, Y., Liang, P., Zhang, J., Li, M., Shen, C., Yang, Z. and Wang, C., 2013. Effects of pH, temperature, and osmolarity on the morphology and survival rate of primary hemocyte cultures from the Mitten Crab, *Eriocheir sinensis*. *In Vitro* Cellular and Developmental Biology Animal. 49. 716-727.
- Huang, H.Z., Yi, L.I., Song, X.H.,
  Wang, Y.L. and Yang, C.G., 2006.
  NH<sub>4</sub>-N stress on immune function of *Eriocheir sinensis*. Oceanologia Et Limnologia Sinica, 37, 198-205.
- Lin, X.T., Zhang, Q.M., Zhang, Q.M., Xu, Z.N. and Ji, X.L., 2000. Advancement of the study on respiratory metabolism of decapod crustaceans. *Journal of fisheries of China*, 12, 575-580.
- Kittaka, J. and Onoda, S., 2002. Effect of temperature on growth and maturity of the king crabs Paralithodes brevipes and P. camtschaticus in the laboratory. *Fisheries Science*, 68, 921-924.
- **Kondzela, C.M. and Shirley, T.C., 1993.** Survival, feeding, and growth of juvenile dungeness crabs from southeastern Alaska reared at different temperatures. *Journal of Crustacean Biology*, 13, 25-35.

- **Leffler, C.W., 1972.** Some effects of temperature on the growth and metabolic rate of juvenile blue crabs, *Callinectes sapidus*, in the laboratory. *Marine Biology*, 14, 104-110.
- McGaw, I.J. and McMahon, B.R., 1999. Actions of putative cardioinhibitory substances on the in vivo decapod cardiovascular system. *Journal of Crustacean Biology*, 19, 435-449.
- Montu, M., Anger, K. and deBakker, C., 1996. Larval development of the Chinese mitten crab *Eriocheir sinensis H. Milne-Edwards* (Decapoda: Grapsidae) reared in the laboratory. Helgolander Meeresunters. 50, 223-252
- Pan, H.Q., 2002. Ecological culture of Chinese mitten crab. China Agriculture Science and Technology Press, Beijing. 221 (in Chinese).
- Ruscoe, I.M., Shelley, C.C. and Williams, G.R., 2004. The combined effects of temperature and salinity on growth and survival of juvenile mud crabs (*Scylla serrata Forskål*). *Aquaculture*, 238, 239-247.
- Shirley, T.C. and Shirley, S.M., 1989. Temperature and salinity tolerances and preferences of red king crab larvae. *Marine Behaviour and Physiology*, 16, 19-30.
- Sulkin, S.D. and Mckeen, G.L., 1996.

  Larval development of the crab cancer magister in temperature regimes simulating outer-coast and inland-water habitats. *Marine Biology*, 127, 235-240.
- Wang, H.Z., Wang, H.J., Liang, X.M. and Cui, Y.D., 2006. Stocking models of Chinese mitten crab

- (*Eriocheir japonica sinensis*) in Yangtze lakes. *Aquaculture*, 255, 456-465.
- Wang, Q., Liu, J., Zhang, S., Lian, Y., Ding, H., Du, X., Li, Z. and Silva, S.S.D., 2016. Sustainable farming practices of the Chinese mitten crab (*Eriocheir sinensis*) around Hongze Lake, lower Yangtze River Basin, China. Ambio, 45, 361-73.
- Wei, L.I., Zhang, Z. and Jeppesen, E., 2008. The response of *Vallisneria spinulosa* (Hydrocharitaceae) to different loadings of ammonia and nitrate at moderate phosphorus concentration: a mesocosm approach. *Freshwater Biology*, 53, 2321-2330.
- Zhang, L.S.,Qu, J.J., Wang, D.D. 2000. Ecological and morphological

- characteristics of populations of Chinese mitten crab (*Eriocheir sinensis*) from Changjiang, Oujiang and Liaohe Rivers and the Quality Identification of their Young Crabs. Fisheriesence and Technology Information, 27, 200-205.
- Zhang, L.S., Zhu, X.C., Yuan, S.Q. 2002. Study on forecast of fishing season of Chinese mitten-handed crab (*Eriocheir sinensis*) seeds at the mouth of Yangtse River. *Fisheries Science and Technology Information*, 29, 56-60.
- **Zou, S.M., Si-Fa, L.I., 2002.** The story of immigration of *Eriocheir sinensis* in Europe and USA. *Journal of Shanghai Fisheries University*, 11, 393-396.