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Effects of climate-induced water temperature changes on the life history of brachyuran crabs

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Abstract

Water temperature is among the most important factors affecting reproduction and development of brachyuran crabs. The increase in mean global temperature resulting from climate change and atmospheric warming subjects all organisms to potential thermal stress. This paper reviews the effects of climate-induce water temperature change on the thermal tolerance, thermal polygon and as expressed by changes in growth, development, thermal resistance, maturation, spawning and embryonic development throughout the brachyuran crab's lifespan. Survival and growth of brachyuran crabs, particularly during moulting, is temperature dependent. Thermal tolerance as depicted in thermal polygons varies among individuals depending on their acclimatization temperature and life stage, size and physiological condition. The mechanism of thermal tolerance and exact parameters of the thermal polygons of brachyuran crabs remain to be elucidated. Cooler water retards growth and delays maturity, causing crabs to begin maturation when they are at larger sizes. Crabs possess a set of behavioural, biochemical and physiological responses that enable them to compensate for temperature fluctuations, but these biological tools have limits.

Key words: aquaculture, climate, crustacean, growth, maturation, thermal.

Introduction

Climate changes occur over time through natural variability but also as a result of human activity. Human activities are responsible for the increase in greenhouse gases in the atmosphere, which have in turn increased the atmospheric and oceanic temperatures. Climate changes are considered a serious problem by the United Nations Framework Convention on Climate Change (UNFCCC). Following the publication of a report assessing the science of climate change by the United Nations Intergovernmental Panel on Climate Change (IPCC), many studies have been completed regarding the subject (Abol-Munafi & Azra 2018). Additional studies regarding climate-induced temperature changes are vital to better understand the biological effects of water temperature. The present investigation showed that 'temperature-related studies' was among of the most frequent keywords on Scopus (when the keyword is climate change; Table 1). The table also showed that the number of publication increased by year and Blackwell Publishing Inc./Wiley-Blackwell is the top publisher of climate-change-related studies. Changes in water temperature have significant effects on marine organisms' life cycles because aquatic ecosystems can be affected by even slight changes in water temperature (Quinn 2017).

Crustaceans are considered important fisheries in many countries, and the influence of climate change poses a serious environmental and economic threat. Brachyuran crabs are recognized for their great potential for aquaculture worldwide because of their broad distribution and market demand, which is expected to rapidly increase during the next few years owing to their nutritional value, excellent flavour and profitability. Increasing knowledge regarding the growth and development of portunid crabs is

Table 1 Quantitative data of climate change as keywords in Scopus and Sciencedirect search engines

Search engine/ Sources	Type of study (%)				Number of publications (past 3 years)			Top publisher†			
	Temperature related studies	Precipitation	Green-house effect	Carbon emission	2016	2017	2018	Blackwell Publishing Inc./Wiley-Blackwell	American Meteorological Society	Reidel Publishing Company	Nature Publishing Group
Scopus	65	20	10	5	26 540	27 721	30 405	7738	4493	3787	3192
Science-direct	70	15	10	5	38 297	44 060	46 828	Data not available			

†Available number of document – updated till June 2019.

important for optimizing their potential for nursery culture (Waiho *et al.* 2018). The current methods of culturing the larval and juvenile stages of brachyuran crabs need optimization to increase the low survival rate during hatching and seed production. In this review, Brachyuran crabs were chosen because they are one of the most diverse groups of crustaceans, currently comprise more than 7000 species, and present a high morphological complexity due to the process of 'carcinification', in which the head and thoracic somites are fused, and the first pereipods and chelipods are located at the side of the body (De Grave *et al.* 2009). They are considered the most diverse group of crustaceans, present in almost all coastal habitats including mangrove forests, rocky shores, sandy beaches and other benthic habitats (De Grave *et al.* 2009). Brachyuran crabs are also cultivated on a large scale for commercial purposes and are considered a source of income for local fishing communities living in coastal areas (Hungria *et al.* 2017; Tavares *et al.* 2018). In addition, they play an important role as predators, prey or debris feeders in the complex food chain of coastal and marine ecosystems.

Thermal tolerance is the ability to acclimatize and thrive during extended exposure to a new thermal regimen (Tepolt & Somero 2014). A thermal polygon is a graphical model using lethal temperature measurements to depict the thermal niche of an animal. The determination of thermal tolerance and creation of thermal polygons for portunid crabs is important for optimizing physiological and reproductive conditions, food intake, growth, behaviour and survival (McLean & Todgham 2015; Azra *et al.* 2018). Studies of the maturation stages are also essential for establishing broodstock production in a hatchery and assessing culture potential, harvest times and population conservation, particularly of ovigerous females (Ikhwanuddin *et al.* 2014). Detailed knowledge of sexual morphology during the early stages of moulting is important for pond culture, benthic settlement, fishery recruitment and identifying future habitats. The effect of a water temperature variation on different life stages of brachyurans needs to be addressed for aquaculture. This review focuses on the development of thermal tolerance in response to water temperature; the creation of more accurate thermal polygons; and the effect of temperature on spawning and embryonic development, growth, survival and sexual maturation of cultured brachyuran crabs as well as discussed means to reduce its effects on reproduction and development. The criteria for evaluating effects of water temperature on life history were derived from original references.

Climate change studies: water temperature

Crabs are poikilothermic and must adapt to changes in water temperature or suffer alterations in their metabolism, reproduction and development. Studies on climate change are used to: (i) assess the effects of global warming on ecosystems; (ii) understand the responses to climate change for predictions' (iii) project climate variability; and finally, (iv) plan for climate change mitigation (Bellard *et al.* 2012). Global warming has already reached 1°C above preindustrial levels and the IPCC mandated limiting this value to 1.5°C. The IPCC stated that by the year 2100, the global average temperature increase will be 5.8°C (Hulme 2016). This increase could significantly alter the life cycle of aquatic organisms by lowering their resilience, population levels, and distribution, and distribution all of which would disrupt ecosystems. Crustaceans in aquaculture are particularly susceptible to harmful effects of climate-induced temperature variability on specific life stages.

Thermal tolerance and thermal polygon

Given the increase in water temperature because of global warming, the creation of accurate thermal polygons of cultured species is essential. Thermal tolerance determinations and their graphical depiction as thermal polygons are frequently used as baselines for identifying lethal water temperatures of cultured animals (Hopkin *et al.* 2006). Analysis of thermal tolerance is important in aquaculture in which animals can experience relatively rapid fluctuations in temperature during transportation (Kir *et al.* 2017). Marine species living near their upper thermal limits are most sensitive to climate-induce water temperature change (Nguyen *et al.* 2011). Some aspects of thermal tolerance and the appearance of a thermal polygon may vary between study populations of the same species. Thermal tolerance values among cultured animals differ depending on their acclimation temperature and life stage, size and physiological condition (Azra *et al.* 2018). Variation in thermal tolerance and thermal polygon values among species and even individuals suggests that these values are species-specific and depend on the environment. If certain species of marine crustaceans, such as brachyuran crabs, tolerate a wider range of temperatures, they can be cultured during both cold and warm seasons. Determining both Critical Thermal Maxima (CTMax) and Critical Thermal Minima (CTMin) defines the thermal polygon limits and can help in deducing which species or individuals have greater thermal tolerance, assuming that the safety ranges between critical temperatures and actual field temperatures are known (Eme & Bennett 2009).

Most studies of brachyurans have used wild-captured adults and little has been recorded for larvae or juveniles because of the difficulty in obtaining them. This information is important for understanding the effects of temperature on growth and adaptability of crabs during different life stages. CTMax and CTMin can be used to determine the optimal temperature for stocking crabs in aquaculture facilities in general. Thermal polygons can significantly change according to an animal's life stage, body size, and locomotive activity. Mobile animals have higher metabolism, higher temperature tolerance ranges and different sensitivities and geographical distributions than their immobile counterparts (Padilla-Ramirez *et al.* 2015). The area of the thermal polygon is ideal for determining the amplitude of CTMax and CTMin zones for defining thermal capacities and predicting how well a certain species will tolerate temperature changes. The thermal polygon area differs among brachyuran crab species depending on their thermal tolerance range. Table 2 shows the quantitative data on thermal tolerance of brachyuran crabs at different acclimation temperatures. The thermal tolerance of selected brachyuran crabs at different acclimation temperatures in the range of 6–36°C resulted in variation in the thermal tolerance between 0°C (for CTMin) and 42.66°C (for CTMax). Thermal polygon and Acclimation Response Ratio (ARR) were also vary between species where 375–1350°C for the thermal polygon area and 0.05–0.61 for ARR respectively.

Impact of water temperature on brachyuran crabs life stages

Most studies have been focused on four aspects of the life cycle of the brachyuran as follows; larval, juvenile, adult and broodstock (more on ovigerous females). Most temperature studies have been performed on the larval and broodstock stages because these are the most important areas of concern for crab aquaculture as shown in Table 3.

Growth, survival and development – larvae and juveniles

The growth, survival and development from the larval to juvenile stages of brachyuran crabs are the most critical parts of crab rearing because they are the most sensitive to water temperature (Azra *et al.* 2018). Additional studies on the relation of water temperature to growth are crucial for optimizing techniques for rearing brachyurans for aquaculture (Martelli *et al.* 2019). A better understanding of the effects of water temperature could improve methods for increasing growth, development and survival. The early developmental stages of brachyuran crabs are the most suitable times for testing methods to promote growth, survival and development. Low temperatures decrease growth, whereas elevated temperatures stimulate growth and affect maturation size. Increasing the temperature shortens intermoult periods promoting faster growth of certain brachyurans. Test temperatures have ranged from 0 to 39°C, and most studies used crabs obtained from the wild with a few using hatchery crabs. To obtain accurate data on growth and development, instar/juvenile crabs should be reared from larvae. Detailed studies on larval and juvenile growth of brachyurans are crucial for (i) understanding and modelling their ecology and population dynamics, (ii) advising management for sustainable aquaculture, (iii) determining age at maturity for projecting the growth cycle, (iv) estimating aquaculture systems costs and (v) identifying potential applications for aquaculture and restocking programmes (Gong *et al.* 2015; Waiho *et al.* 2018).

On sexual maturation – adult/broodstock

A global study on the size at the onset of sexual maturity (SOM) in brachyuran crabs showed that SOM varied among species and locations. However, because most researchers used wild crabs, little is known regarding SOM in brachyuran crabs reared in captivity. Previous SOM studies used four criteria: (i) morphometric analysis (allometric growth), (ii) physiological analysis (microscopic examination of histological sections), (iii) behavioural analysis (presence of sperm plugs and direct mating behaviour), and (iv) functional analysis (the presence of eggs) (Waiho *et al.* 2017). SOM depended on species, methods

Table 2 Quantitative data on thermal tolerance of brachyuran crabs at different acclimation temperatures

Crab species, common name and sources of the crabs	Acclimation temperature	Thermal tolerance (°C)	Thermal polygon (°C^2)	Acclimation Response Ratio	References
Callinectes sapidus, Blue crab (adult & juvenile) – wild sources	6–30	0.0–39.0	1186–1350	N/A	Tagatz (1969)
Carcinus maenas, Green crab – wild sources	8–22	31.3–35.8†	N/A	0.17–0.61	Cuculescu *et al*. (1998)
Portunus pelagicus, Blue swimming crab (adult) – wild sources	15–35	12.28–42.66	519.7	0.05–0.45	Qari (2014)
P. pelagicus, Blue swimming crab (instar/juvenile) – hatchery sources	20–36	18.33–39.62	375	0.245–0.508	Azra *et al*. (2018)
Cancer antennarius, Red shore crab – wild sources	15–24	31–33	N/A	0.10–0.30	Padilla-Ramirez *et al*. (2015)

†Value of thermal tolerance were available only for CTMax.
N/A, not available.

Table 3 Number of publication available in Scopus search engine related to the species and life-history stage of brachyuran crabs

Scopus search engine	Type of life-history stage (%)				Top brachyuran crab species						
	Larval	Juvenile	Adult	Broodstock/ ovigerous females	*Carcinus maenas*	*Callinectes sapidus*	*Chionoecetes opilio*	*Scylla serrata*	*Eriocheir Sinensis*	*Chaceon affinis*	*Portunus pelagicus*
Number of publication†	40	10	20	30	133	103	64	48	39	38	32

†Available number of document – updated till June 2019.

used to determine onset size, population density, spatial and temporal distribution, and temperature (Ondes *et al*. 2017). Previous studies have shown that most portunid crabs are sexual dimorphic in abdominal shape during the later stages compared to that of other brachyuran species (Ondes *et al*. 2017; Waiho *et al*. 2017). Obtaining information regarding SOM is crucial because it is important for determining reproductive output and population health.

Knowledge regarding the effects of water temperature on brachyuran reproduction is necessary for establishing optimal temperatures for accelerating maturation (Waiho *et al*. 2016). It is well-known that water temperature modifies reproduction and maturation in crustaceans, particularly crabs (Olson *et al*. 2018). In general, cooler temperatures retard growth and delay maturity, causing the animals begins maturation when they are at larger sizes. Decreasing the size of mature female crabs may decrease reproduction because body size is among of the factors limiting fertility. This information directly affects aquaculture, the problem of decreasing natural stocks of crabs and the changing quality of broodstock. At very low temperatures, crabs enter dormancy (i.e. slow metabolism), which greatly retards their growth. In marine crustaceans, increased water temperatures reduced the time needed for maturity as well as the size at maturity. How long-term temperature changes will affect the maturation process of portunids remains to be investigated.

On spawning and embryonic development – berried females

An increased understanding of spawning and embryonic development of brachyuran crabs is important for successful production of berried females in hatcheries. Spawning and embryonic development are species-specific and temperature influences the development of brachyuran eggs including egg size, egg-mass, incubation period and hatching time (Zeng 2007; Fischer *et al*. 2009). Most brachyuran species are affected by water temperature. Increasing the temperature from 1 to 35°C decreased embryonic development, while the egg size increased at lower temperatures (Hamasaki *et al*. 2003; Webb *et al*. 2007). Further, hatching occurred earlier at higher temperatures, and development of embryos and production of berried females was favourable for aquaculture.

Impact on brachyuran crab aquaculture, future challenges and recommendations

Research regarding the effects of climate-induce water temperature change allows one to optimize aquaculture conditions for the future. However, as addressing climate-induce water temperature change has not been a priority in the aquacultural industry, only limited data are available. With the unimpeded increase in anthropogenic greenhouse gases along with natural variation, global warming will continue to increase ocean water temperatures. Controlling water temperature in aquacultural facilities requires power, which results in higher costs; however, increasing temperature shortens the intermoult periods promoting superior growth of certain brachyurans (Kuhn & Darnell 2019). Finding means to sustain seed production in a hatchery under a constantly deteriorating global climatic condition is an obstacle. Any change in water temperature in the crabs' environment can significantly influence their metabolism, reproduction and development, thus disrupting their natural ecosystem. Water temperatures outside of the optimal range cause a significant decline in the number of juveniles. Crabs possess a set of morphological, behavioural, biochemical and physiological responses that enable them to compensate for temperature fluctuations – but only up to a point. We recommended that further study should be done on the effects of water temperatures on sex determination and population status of the certain brachyuran species.

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