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Temperature effects on the molting, growth, and lipid composition of newly-settled red king crab

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Abstract

Red king crab (RKC) (*Paralithodes camtschaticus* Tilesius, 1815) is one of the most important fishery resource species in Alaska. It is threatened by heavy fishing pressure and changing climate conditions, yet little is known about the species' first year of post-settlement life. This study was undertaken to explore how temperature mediates growth and energy allocation in newly metamorphosed juveniles. RKC were reared using four temperature treatments ranging from 1.5° to 12 °C for a period of 60 days, both individually and in low-density populations. Temperature had no significant effect on survival of RKC, and there was no consistent difference in survival between individually cultured crabs and those in populations. Growth was very slow at 1.5 °C, and increased rapidly with temperature with both a contracted intermolt period and small increase in growth increment. Twenty percent of the crabs held at 1.5 °C never molted, while more than 90% of the crabs in 12 °C reached juvenile stage 4 or higher. Overall growth increased as an exponential function of temperature, with slightly higher growth rates observed in populations than for isolated individuals. Growth records for individuals revealed an inverse exponential relationship between water temperature and intermolt period. There was also a small increase in growth increment from juvenile stage 1 to stage 2 with increasing temperature that appeared to be linear. Lipid class analysis revealed a trend towards higher proportions of storage lipids in larger crabs cultured at 12 °C than in crabs cultured at low temperatures. High proportions of essential fatty acids in all crab groups coupled with elevated levels of triacylglycerols in 12 °C animals, indicate that rapid growth does not negatively affect condition in juvenile RKC. Data provided by this study will help to model temperature-dependent growth and survival in the field, and assist in designing the best possible temperatures and diets for hatchery production of seed stock intended for enhancement of depleted RKC stocks.

Introduction

Temperature is a dominant environmental factor that mediates the behavior, physiology, growth, survival, distribution, and recruitment of ectothermic animals living in temperate and high latitudes. Consequently, climate-driven changes in ocean conditions can cause significant fluctuations in the distribution and abundance of marine populations (Perry et al., 2005). In the Gulf of Alaska and Bering Sea, oceanographic regimes linked to climate conditions occur on a multi-decadal scale (Hollowed et al., 2001, Peterson and Schwing, 2003, Hunt et al., 2002), and these climate cycles have been linked to major temporal shifts in the composition of marine fish and invertebrate communities (e.g., Anderson and Piatt, 1999). Longer-term trends in sea surface warming and loss of sea ice have already been observed in the Gulf of Alaska (Royer and Grosch, 2006) and Bering Sea (Stabeno et al., 2007), and the potential impacts on economically important species are large (e.g., Orensanz et al., 2004).

Red king crab (*Paralithodes camtschaticus*) (RKC) was the most economically valuable crustacean fishery in Alaska from the late 1960s, until the population collapse in the early 1980s (Orensanz et al., 1998, Zheng and Kruse, 2000). Both over-harvest and unfavorable environmental conditions probably contributed to low fishery recruitment (Dew and McConnaughey, 2005, Orensanz et al., 1998). Various fishing closures have been imposed in the Gulf of Alaska and Bering Sea for more than two decades, but the stocks have not recovered substantially. Consequently, this study was designed in the context of two broad themes — understanding how RKC growth and survival may be affected by warming trends expected in Alaska, and determining how temperature might be used in developing the best possible methods for culturing crabs in hatchery setting for the growing stock enhancement effort (Daly et al., 2009).

Relatively little is known about the first year of post-settlement life in RKC, particularly with respect to how temperature affects behavior, growth, and energy allocation. Field observations provide some insights. For example, several studies present growth models for RKC (Weber, 1967, Balsiger, 1974, Stevens, 1990, Stevens and Munk, 1990). These studies were aimed primarily at determining age-at-recruitment and age-at-maturity; however, it is understood that growth of juveniles is temperature-dependent, and Loher et al. (2001) concluded that differences in growth rates among different year classes in Bristol Bay were related to temperature variation. For example, slow apparent growth in the 1976-year class was associated with a period of very cold bottom water temperatures in the Bay (near 1 °C) during the early summer survey period. As yet, the effects on recruitment are unknown.

Growth in crustaceans is affected by two different variables: a) intermolt period — the duration between two successive molts, and b) molt increment or growth increment — the increase in size that occurs between one instar and the next. Hartnoll, 1982, Hartnoll, 2001 pointed out that temperature is the most important extrinsic factor affecting the intermolt duration, and there are many examples of decreasing intermolt period with increasing temperature. However, effects of temperature on molt increment are variable, with many crustaceans showing no variation over a wide range of temperature (reviewed by Hartnoll, 1982).

Lipids play a fundamental role in the physiology of cold-water marine organisms where they provide both a high density source of energy and vital components of cellular membranes (Copeman and Parrish, 2003). Previous studies have shown that triacylglycerols (TAG) are the major storage lipid class in crustacean larvae and juveniles (Nates and McKenney, 2000), and TAG levels cycle with the molt cycle (Ouellet and Taggart, 1992). Other major lipid classes in crabs include sterols (ST) and phospholipids (PL), which form important constituents of cellular membranes. Relative improvements in both larval and juvenile condition in marine species, such as Atlantic cod (*Gadus morhua* Linnaeus 1758), herring (*Clupea harengus* Linnaeus, 1758) and American lobster (*Homarus americanum* H. Milne Edwards, 1837) have been attributed to elevated total lipid, TAG per dry weight, and TAG/ST ratios (Fraser, 1989, Copeman et al., 2008).

The importance of dietary polyunsaturated fatty acids (PUFA) to the culture of juvenile crustaceans has been investigated for several crabs (Suprayudi et al., 2004, Zmora et al., 2005), lobster (Limbourn and Nichols 2009) and shrimp (Lavens and Sorgeloos, 2000). Crustaceans generally require PUFA such as docosahexaenoic acid (DHA, 22:6n−3), eicosapentaenoic acid (EPA, 20:5n−3), and arachidonic acid (AA, 20:4n−6) at minimum levels in the diet as they cannot be formed *de novo* from shorter chain dietary precursors

(Merican and Shim, 1996, Holme et al., 2007). Membrane lipids are known to play an important role in thermal adaptation of marine ectotherms (Dunstan et al., 1999, Hall et al., 2000, Hall et al., 2002).

This study was designed to evaluate the role of water temperature on molting frequency, growth, lipid composition, and survival in the earliest benthic stages of red king crab. Four temperatures were tested (1.5° to 12°C), spanning the normal range of distribution encountered by newly-settled RKC in the field. Little growth was observed in crabs held at the coldest temperature; therefore, a subset of these crabs was tested for compensatory growth with an increase in temperature to 12°C. Lipid and fatty acid analyses were made at the end of the 60-day growth period. This yielded the first description of lipid class and fatty acid composition of RKC juveniles, and the effects of temperature on crab condition and energy allocation. The results of these experiments are relevant to both aquaculture and changing climate conditions in Alaska.

Section snippets

Experimental animals

Red king crabs for this study were supplied by the Alutiiq Pride Shellfish Hatchery in Seward, Alaska. Twelve ovigerous female RKC were collected with baited pots set in Bristol Bay, Alaska, during fall 2008 and maintained at the hatchery on chopped herring and squid until their larvae were released in May 2009. Larvae from each female were mixed and reared in 1200L cylindrical tanks until the first juvenile instar (C1) was achieved. The newly-settled crabs were fed daily with *Artemia* nauplii…

Overall crab survival and growth

The effect of temperature on survival in population cultures was relatively small (Table 1), and differences were not significant at either 30 (ANOVA, $F_{3,11}$=2.328, p=0.131) or 60days ($F_{3,11}$=1.307, p=0.321) because of substantial variation. Overall survival at the end of the experiment was only 5.5% higher in individually cultured crabs than in populations, but the differences were not consistent across temperatures (Table 1).

Average growth rate of RKC over the 60 day experiment increased…

Individual versus population cultures

Culturing RKC individually required higher material and labor costs than culturing populations, and provided no great advantage in terms of survival. High mortality predicted for populations at high temperatures, because of cannibalism on molting crabs, was not a significant problem in the primary experiment. Instead, low mortality throughout the temperature treatments may have been a result of relatively low crab densities in the population treatments (151 crab m^{-2} maximum at the beginning of…

Acknowledgements

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> …This may reflect efficient food conversion in the cold during long-term experiments (Siikavuopio and James, 2015; Windisch et al., 2014). The deep-water living adults and the shallow-water juveniles of red king crab may differ in temperature tolerance and changes in cellular energy allocation (Stiansen et al., 2009; Stoner et al., 2010; Long and Daly, 2017), which may relate to the expression of genes involved. Juveniles kept at either 10.5, 12.5 or 14.5 °C for 20 days showed strong effects of acclimation on transcriptome level.…

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