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How climate change-induced temperature increases impact crustacean aquaculture

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By integrating physiological, immunological, and ecological evidence, this review identifies key knowledge gaps and highlights opportunities to improve climate resilience in crustacean aquaculture

A comprehensive review of the effects of climate change-induced temperature increases on crustacean aquaculture – integrating physiological, immunological, and ecological evidence – identifies key knowledge gaps and highlights opportunities to improve climate resilience in crustacean aquaculture. Enhancing the resiliency of crustacean aquaculture requires improved understanding of physiological responses, emerging technologies, and adaptive management practices. Photo of a mud or mangrove crab (*Scylla serrata*) – an economically important cultured species in the Indian and Pacific areas – by Mark Clarke (CC BY 4.0, https://creativecommons.org/licenses/by/4.0,, via Wikimedia Commons).

Climate change is recognized as one of the most severe environmental threats, affecting aquaculture by altering the physical and physiological conditions of farmed species and impacting ecosystem productivity and resource availability. Marine crustaceans are **particularly vulnerable** (https://doi.org/10.3390/ani11041146) to climate-induced temperature rise due to their narrow thermal niches and proximity to thermal tolerance. As **temperatures rise** (https://doi.org/10.1016/j.ecoenv.2021.112412) beyond these thresholds, it leads to increased oxygen demand, metabolic shifts, reduced feed intake, and suppressed immune function. Climate change not only elevates temperature but also intensifies co-occurring stressors, such as weakened exoskeletons due to ocean acidification, hypoxia, salinity fluctuations, and pathogens emergence.

These compounded effects increase vulnerability in crustaceans, making it essential to understand both the direct and indirect consequences for effective aquaculture and fisheries management.

Understanding the direct and indirect effects of climate change on crustaceans is critical for effective aquaculture and fisheries management. Addressing these challenges requires **integrated strategies** (https://doi.org/10.1016/j.jtherbio.2018.04.002) focusing on conservation and sustainability, especially given crustaceans' sensitivity to thermal stress and climate variability.

This article – **summarized** (https://creativecommons.org/licenses/by/4.0/) from the **original publication** (https://doi.org/10.1016/j.aaf.2025.08.008) (Daunde, V.V.Y. et al. 2025. Effects of climate change-induced temperature rise on crustacean aquaculture: A comprehensive review. *Aquaculture and Fisheries*, available online 23 August 2025) – discusses a review that examined the impact of elevated temperatures on growth performance, food intake, molting, immune response, and survival of major farmed crustaceans, including shrimp, prawns, crabs, lobsters, and crayfish

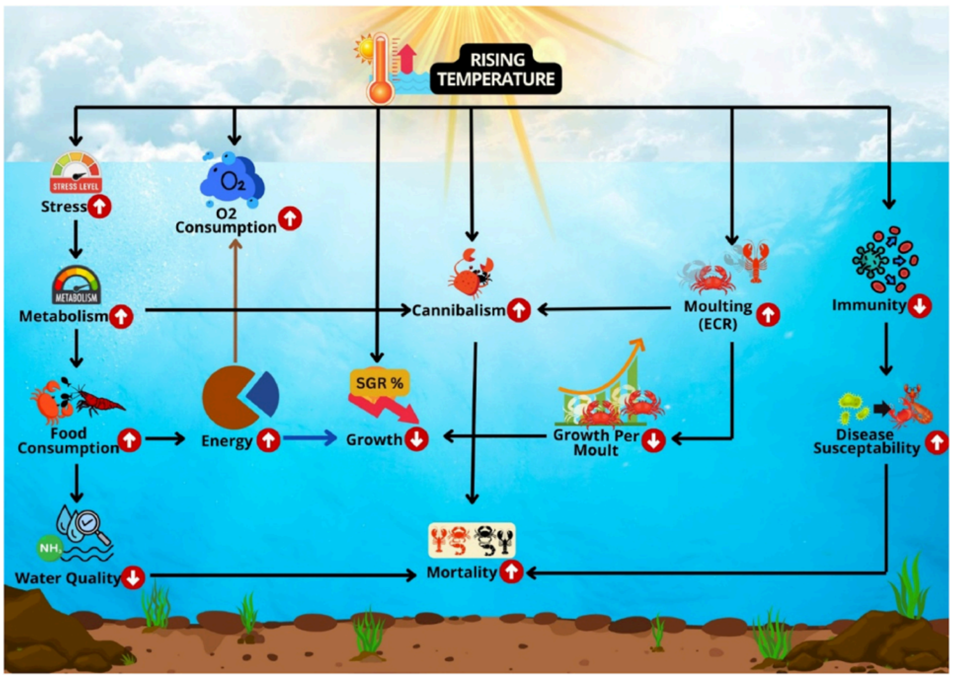

Fig. 1: Graphical summary of the effects of climate change induced temperature rise on crustaceans in aquaculture systems. Adapted from the original.

Literature was sourced using structured keyword-based searches in major academic databases including PubMed, Scopus, ScienceDirect, and Google Scholar. Combinations of search terms such as “thermal stress,” “temperature,” “shrimp,” “crustaceans,” “growth,” “immunity,” and “aquaculture” were used. Studies were included if they involved controlled exposure of crustaceans to elevated temperature and evaluated relevant biological parameters. Exclusion criteria included review papers, conference abstracts, meta-analyses, and studies that lacked temperature-specific experimental design or were unrelated to aquaculture.

Overview of species and their temperature range

Research on decapod crustaceans primarily focuses on understanding the thermal preferences and tolerances of various species relevant to aquaculture. Fig. 2 shows the temperature range (from optimal to elevated levels) for the selected crustacean species, highlighting their thermal tolerance limits and ability to adapt to changing environmental conditions. Research on the impact of elevated temperatures on prawns and shrimp has mainly concentrated on species like the whiteleg shrimp (*Penaeus vannamei*) with higher temperatures tested ranging from 29 to 40 degrees-C and the giant freshwater prawn (*Macrobrachium rosenbergii*), with higher temperature ranges from 33 to 38 degrees-C, especially at temperatures around 34 degrees-C.

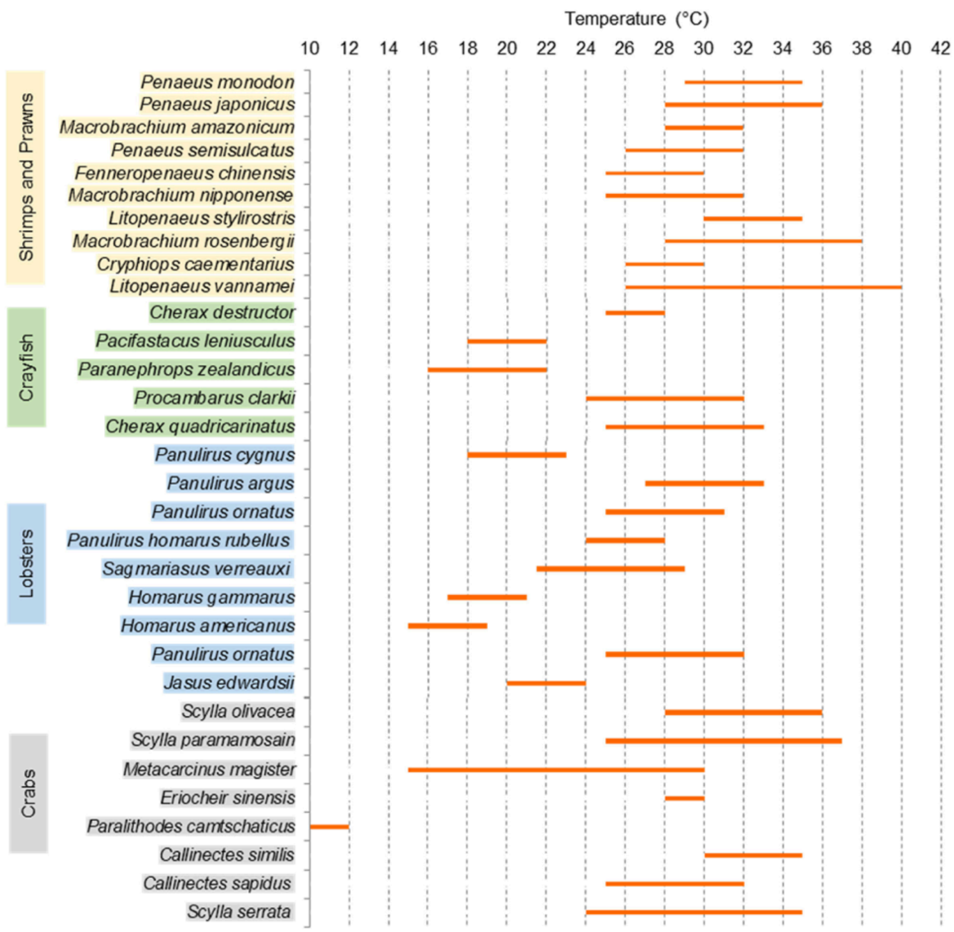

Fig. 2. Temperature range (optimum to higher) for various decapod crustacean species relevant to aquaculture.

Other species, such as the Oriental river prawn (*Macrobrachium nipponense*) have been studied at higher temperatures, specifically at 30 and 32 degrees-C. Similarly, the Chinese white shrimp (*Fenneropenaeus chinensis*) has been studied at 30 degrees-C; the black tiger shrimp tiger prawn (*P. monodon*) at 35 degrees-C; the kuruma prawn (*P. japonicus*) at 36 degrees-C; the Amazon river prawn (*M. amazonicum*) at 32 degrees-C; and the green tiger prawn (*P. semisulcatus*) at 32 degrees-C. In addition, the blue shrimp (*Litopenaeus stylirostris*), and the South American freshwater shrimp (*Cryphiops caementarius*) have been studied at higher temperatures of 35 and 30 degrees-C, respectively.

For crabs, the focus is primarily on mud crab species such as giant mud crab (*Scylla serrata*), green mud crab (*S. paramamosain*), and orange mud crab (*S. olivacea*) with higher temperatures studied ranging from 32 to 37 degrees-C across these species, which are commercially valuable due to their size and availability. Other species examined include the blue crab (*Callinectes sapidus*) at higher temperatures of 30-32 degrees-C; lesser blue crab (*C. similis*) at 35 degrees-C; red king crab (*Paralithodes camtschaticus*) at 11-12 degrees-C. Also, the Chinese mitten crab (*Eriocheir sinensis*) and Dungeness crab (*Metacarcinus magister*) both at 30 degrees-C.

Lobster research predominantly involves spiny lobsters, with wide range of temperature tolerance for species like *Panulirus* spp. and *Sagmariasus* spp., valued for their aquaculture potential, disease resistance, rapid growth (for certain species), and adaptability to various environments. Spiny lobster species studied include the ornate spiny lobster (*Panulirus ornatus*), East coast rock lobster (*P. homarus*), Caribbean spiny lobster (*P. argus*), Western rock lobster (*P. cygnus*), and green rock lobster (*Sagmariasus verreauxi*) having high temperature range from 23 to 33 degrees-C. Research also includes clawed lobsters (*Homarus* spp.), American lobster (*H. americanus*) and European lobster (*H. gammarus*) studied at higher temperatures from 19 to 21 degrees-C, and red rock lobsters (*Jasus edwardsii*) studied at 22 and 24 degrees-C.

In crayfish research, the Australian freshwater crayfish (*Cherax quadricarinatus*) receives the most attention, particularly for its adaptability to tolerate wide temperature range. It is highly regarded for aquaculture and the aquarium trade because of its adaptability, ease of cultivation, and strong market demand. The higher temperature range studied for Australian freshwater crayfish was between 30 and 33 degrees-C.

The interconnected impacts of climate change and elevated temperatures on shellfish and aquaculture are shown in Fig. 3. The green cluster links shellfish and molluscs to aquaculture and human activities, highlighting the threats climate change poses to seafood production, especially from ocean acidification and temperature variations. The blue and yellow clusters indicate the impact of increased water temperatures on metabolism, reproduction, and survival, disrupting growth dynamics and threatening overall marine biodiversity. These changes pose significant challenges to the aquaculture industry, affecting species resilience, productivity, and long-term sustainability.

Fig. 3: VOSviewer keyword co-occurrence clustering view. The green cluster represents the connection between shellfish, mollusks, aquaculture, and human activities. The blue cluster indicates the impact of increased water temperatures mainly on animal's physiological processes. The yellow cluster highlights the disruption of growth dynamics and threats to marine biodiversity.

Adaptive strategies for aquaculture

Adaptive strategies in aquaculture are critical for addressing the challenges posed by climate change, particularly rising water temperatures, which can significantly affect the health, growth, and productivity of aquaculture species. As environmental conditions change, it becomes crucial to implement strategies that help sustain aquaculture systems by reducing temperature stress on organisms, improving resilience, and promoting sustainable practices. The effects of rising temperatures vary considerably across geographical regions due to differences in species, farming systems, and adaptive capacity.

Fig. 4: Strategies to combat temperature rise in crustacean aquaculture. Adapted from the original.

Rising temperatures and associated climate-driven stressors are projected to alter aquaculture production potential globally. Asia – currently responsible for approximately 90 percent of marine cultured biomass – is at **significant risk of production declines** (https://doi.org/10.1016/j.biocon.2017.09.012) for finfish and bivalves. Tropical regions such as South and Southeast Asia, which depend heavily on small-scale aquaculture systems with limited adaptive capacity, are especially vulnerable to temperature extremes. In these areas, thermal stress, ocean acidification, and declining primary productivity may reduce growth performance, particularly in species already near their **thermal tolerance limits** (https://doi.org/10.1093/icesjms/fsw052) or sensitive to multiple stressors.

Africa ranks among the most climate-vulnerable regions globally. Many of its aquaculture systems depend on freshwater sources that are highly sensitive to climate change. Prolonged droughts and erratic rainfall, driven by global warming, reduce water availability and quality, leading to pond drying, salinity fluctuations, and eutrophication – factors that **severely impact aquaculture productivity** (https://doi.org/10.1111/lre.12331). In temperate countries such as South Korea, aquaculture is particularly susceptible to climate change due to its heavy dependance on open marine systems. Over the past decade, 53 percent of aquaculture-related damages from natural disasters in Korea have been attributed to rising sea surface temperatures.

To address these challenges, region-specific adaptive strategies have been developed. In Sri Lanka, small-scale shrimp farmers collaborate using a shared farming calendar known as zonal crop calendar system (ZCCS) to manage disease and climate risks. This community-based approach blends traditional knowledge with government recommendations, allowing them to adjust practices based on past experiences. Mediterranean countries are promoting **resilient aquaculture systems** (https://doi.org/10.1111/j.1753-5131.2012.01071.x)through the adoption of intensive cage culture, hatchery-bred sterile stocks, plant-based feeds, and ecosystem-based policies such as Integrated Coastal Zone Management (ICZM) and the Ecosystem Approach to Aquaculture (EAA) to enhance sustainability and climate resilience.

Southeast Asian and African countries are increasingly adopting Integrated Multi-Trophic Aquaculture (**IMTA** (https://doi.org/10.3389/fmicb.2012.00348)) and polyculture systems to enhance nutrient efficiency and climate resilience. IMTA systems are being implemented in countries such as those in West Africa, as well as in India, and Vietnam, where they improve resource use efficiency, reduce greenhouse gas emissions from traditional agriculture, and contribute to agroecosystem enrichment.

Improved extensive shrimp farming systems have demonstrated greater sustainability and climate resilience, particularly for small-scale farmers. In one example, over a 10-year period, strategic government investment of USD 191 million in adaptation measures supported aquaculture exports worth USD 2.7 billion. Although this represented just 0.7 percent of total export revenue, it provides a compelling case for continued public funding to support aquaculture development. Such investments reduce the economic burden on smallholders, improve sectoral resilience, and support long-term national goals for sustainable aquaculture and export growth.

"Threatened by climate change, Maine oyster grower adapts how his business 'interacts with the planet' (https://www.globalseafood.org/advocate/threatened-by-climate-change-maine-oyster-grower-adapts-how-his-business-interacts-with-the-planet/)"

Research gaps and future directions

Despite advances in understanding climate change impacts on crustacean aquaculture, key research gaps impede effective mitigation and adaptation. A primary gap is the limited mechanistic insight into thermal stress in decapod crustaceans. Elevated temperatures affect growth, molting, and survival, yet underlying molecular and cellular processes are unclear. Thermal stress impairs immunity, but its exacerbation of disease outbreaks is underexplored; future work must examine temperature effects on pathogen persistence, virulence, and host–pathogen interactions for better disease management.

Another gap involves species- and life stage-specific thermal tolerance. Thresholds exist for some species but often cover single stages or narrow ranges. Comprehensive data on larval, juvenile, and adult responses are needed for tailored management, alongside studies of ecological and economic consequences like altered predator-prey dynamics, food web shifts, and species distribution changes.

Limited knowledge persists on species-specific thermal thresholds for specific dynamic action (SDA) suppression and nutrient assimilation across life stages. Studies typically address short-term responses in few species, neglecting long-term adaptations, interspecific variation, and digestion-metabolic efficiency impacts under fluctuating or polyculture conditions.

Methodological inconsistencies – small samples, variable ramping protocols, brief exposures, and lack of field-relevant replication – hinder generalizations. Differences in water quality, diet, molting stage, and genetics complicate comparisons. Standardized, long-term, factorial designs mirroring commercial settings are essential.

To address these research gaps, key future directions include developing robust, species-specific thermal tolerance models integrating ecological, developmental, and physiological data for precise adaptation strategies. Biotechnological tools like RNAi hold promise for boosting disease resistance under thermal stress, but require further evaluation of feasibility, scalability, and environmental safety in aquaculture, especially for GMOs.

Long-term, large-scale monitoring of temperature fluctuations and biological impacts is critical for adaptive management. Policy frameworks must support small-scale producers in implementing climate-resilient technologies and practices to ensure inclusive adaptation. Future research must shift from single-stressor to multi-stressor frameworks, as crustaceans face concurrent temperature, salinity, and hypoxia stresses with synergistic or antagonistic effects.

Multifactorial experiments and systems modeling are needed to assess combined impacts on metabolism, molting, immunity, and disease across life stages. Integrating microbiota and gene expression analyses could reveal adaptive responses, informing targeted interventions.

Finally, climate-adaptive technologies – such as recirculating aquaculture systems (RAS), integrated multi-trophic aquaculture (IMTA); and biofloc technology (BFT) – show potential, but gaps remain in economic viability, scalability, and long-term ecological effects across contexts. Prioritizing evaluations under diverse climate scenarios will guide context-specific adoption.

"As ocean acidification threatens the shellfish industry, this California oyster farm is raising oysters resistant to climate change (https://www.globalseafood.org/advocate/as-ocean-acidification-threatens-the-shellfish-industry-this-california-oyster-farm-is-raising-oysters-resistant-to-climate-change/)"

Perspectives

Rising water temperatures associated with climate change present a substantial threat to crustacean aquaculture, affecting both biological performance and system stability. Elevated temperatures increase metabolic rates, oxygen demand and oxidative stress, often impairing feed efficiency and growth performance. While molting frequency may rise under thermal stress, this is frequently accompanied by reduced size gain, increased energy expenditure, and compromised survival. Temperature-induced stress also alters feeding behavior and disrupts immune responses, increasing the susceptibility of farmed crustaceans to disease outbreaks.

Moreover, warming aquatic environments exacerbate hypoxia and degrade water quality, further impairing physiological function and hindering production. These temperature-driven effects extend beyond individual organisms, influencing seed availability, species distribution, and the ecological balance of aquaculture systems. Therefore, targeted adaptation strategies are essential. While innovative technologies and integrated farming systems offer potential solutions, their success depends on species-specific suitability, economic feasibility, and context-specific implementation.

Ultimately, enhancing the resilience of crustacean aquaculture under climate-induced thermal stress will require a combination of improved understanding of physiological responses, responsible application of emerging technologies, and adaptive management practices tailored to local ecological and socio-economic realities.

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