

Climate change impact: Implications of shortening winters and rising sea water temperatures on captive marine fish brood stock management in Abu Al Abyad Island fish hatchery, Abu Dhabi, United Arab Emirates

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Abstract

Rapidly warming oceans temperatures and the occurrence of marine heatwaves are increasing at unprecedented rates and is further expected to increase the vulnerability of the already extreme marine environment of the relatively shallow Arabian Gulf to climate change impacts. The region's marine ecosystems are under ever-increasing pressures due to activities associated with the rapid urban development, making the Arabian Gulf one of the highest anthropogenically impacted regions in the world. Winters have shortened and temperatures have risen significantly over the last 24 years. In the channel waters of Abu Al Abyad Island, part of the southern Arabian Gulf, the average low winter sea surface temperature (SST) in January/February of $16.71 \pm 0.9^\circ\text{C}$ recorded during the years 2001-2004 increased to $18.28 \pm 0.7^\circ\text{C}$ (an increase of 1.57°C) during the same period in 2020-2024. Similarly, the average high summer (July/August) SST of $34.75 \pm 0.4^\circ\text{C}$ recorded in the years 2001-2004 increased to $36.04 \pm 0.7^\circ\text{C}$ (an increase of 1.3°C) during the same period in 2020-2024. At the Aquaculture and Marine Studies Center (AMSC), Abu Al Abyad Island, Abu Dhabi, spawning data for Goldlined seabream (*Rhabdosargus sarba*), Silver black porgy (*Sparidentex hasta*) and White-spotted rabbitfish (*Siganus canaliculatus*), recorded during these years, showed a significant declining trend ($P < 0.05$) in the duration of the spawning window relative to the optimal thermal regime for spawning of each species. Adoption of advanced technologies like climate controlled Recirculatory Aquaculture Systems (RAS) and selective breeding is recommended for the brood stock managers, to counter the negative effects of climate change.

Keywords: Climate Change; Fish Brood Stock; Spawning Window; United Arab Emirates

1. Introduction

Changes in the ambient environmental factors like temperature, photoperiod, water currents and tidal amplitudes, etc. greatly influence the physiology, reproduction, behavior and ecology of all aquatic organisms and fish are no exception to this [1, 2, 3]. Changes in the ambient temperature and photoperiod most likely leads to either advancement or delay in the reproductive events of seasonal breeders, and thus there is only a short period in the annual reproductive cycle when the conditions are most suitable for reproduction for many seasonal breeders including fish and many phases in the reproductive cycle, such as gonadal development, spawning and gonadal regression are strongly influenced by ambient water temperature. According to some recent studies, climate-driven warming is already, negatively impacting teleost reproductive capacity, leading to reduced gamete quality and reproductive failure in some species [4]. This article briefly reviews the climate change induced changing sea water surface temperature (SST) patterns over the years in Abu Al Abyad channel waters (part of the southern Arabian Gulf) where brood stock fish required for the hatchery operations are held in a near shore open cages and its implications on the reproductive window (the duration when fish are reproductively active), of Goldlined seabream, *Rhabdosargus sarba* (locally known as Gabit), Silver black porgy,

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Sparidentex hasta (locally known as Sobaity) and White-spotted rabbitfish, *Siganus canaliculatus* (locally known as Safi) and also possible solutions to overcome this problem. This information is expected to provide guidance in developing sustainable techniques in aquaculture hatchery operations in the light of changing climate as well as a starting point for planners, policy-makers and practitioners who are involved in this sector related to aquaculture hatchery development in the United Arab Emirates (UAE).

2. The Southern Arabian Gulf environment

The Arabian Gulf, a biogeographic sub-province of the northwestern Indian Ocean, is located in the subtropics between 24°N and 30°N latitude and 48°E and 57°E longitude and represents one of the most extreme marine environments with the greatest anthropogenic impact. Being geographically situated in the subtropics, the surrounding arid environment results in the summer climate being tropical, its climate is transitional between tropical and subtropical and occurs at the subtropical high-pressure zone that results in low cloud cover, limited precipitation, high solar insolation and high evaporation rates that results in unusually extreme marine environmental conditions and more so in the very shallow southern basin along UAE's Abu Dhabi coast [5,6,7,8,9]. During hot summer months, the Southern Arabian Gulf, which is in the photic zone, extending to only 15 m depth through much of its extent [10] is the hottest sea on the planet, particularly in the shallow southern basin where sea surface temperatures (SSTs) regularly exceed 36°C in the months of July and August, due to its shallow depth and relative isolation, and annual average SSTs range by 20°C [11,7], with summer SSTs of >36°C and winter minima of 12°C [12]. The region's high evaporation rates and very limited freshwater input also cause extreme salinity, with values averaging 42 ppt, increasing to 50 ppt in the southern bays and lagoons [13]. Rapidly changing global climate is having pronounced effects in this Gulf that exceeds even the worst-case scenarios predicted for much of the tropics for the next century and since the 1980s, SSTs in the Gulf have increased by 0.4°C per decade, double the global average, with warming rates even higher in more shallow and constrained areas [14,15,16]. These SST increases have already caused considerable degradation in the Gulf's marine ecosystems, with coral reefs, the most diverse of the coastal ecosystems in the region, having been particularly heavily impacted [17]. It has also been suggested that changes in temperatures may affect the highly seasonal spawning times/patterns of commercially important fin fish, with cascading effects on population dynamics and abundance for species of economic importance to commercial fisheries [10]. Globally the frequency and intensity of marine heat waves (MHWs) will become extreme under global warming, probably pushing marine organisms and ecosystems to the limits of their resilience and even beyond, which could cause irreversible changes [18]. As a consequence of the warming gulf waters, decreased oxygen solubility has also been noted leading to oxygen decreases in the surface waters [19]. It has been projected that an increase of 2 to 5.5°C in air temperature coupled with a decrease in precipitation by the end of the 21st century, will lead to shorter winters, hotter and dryer summers, increased weather variability, and more frequent extreme weather events which will directly impact the SSTs in the Arabian Gulf [20]. The world's ocean temperatures and the occurrence of MHWs are increasing at unprecedented rates leading to extreme climatic events [21]. The primary driver of marine heatwaves in the Arabian Gulf is its shallow, semi-enclosed nature, which leads to extreme SSTs during the summer, increasing the region's susceptibility to these events [22,23].

3. The anthropogenic factors

Rising sea temperatures is predominantly attributed to climate change, which is generally also instigated by anthropogenic activities [24]. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. The region's marine ecosystems are under ever-increasing pressures associated with the rapid development of economic, social and industrial activities, making the Arabian Gulf one of the highest anthropogenically impacted regions in the world. The frequency of such environmental disturbances is increasing, and are being further exacerbated by anthropogenic stressors caused primarily by rapid population growth. The growth rate of populations in the Gulf nations is nearly double that of the global average, suggesting that population-related pressures are likely to accelerate [6,20,25].

In the UAE, the impacts originating from coastal urbanization and industrial pollution have contributed to widespread degradation and loss of various other important coastal ecosystems such as sabkhas, mudflats, and mangrove forests [26], while many fish populations are becoming increasingly depleted due to overexploitation [27]. Aside from continuing encroachment of coastal development into remaining natural habitats to accommodate growing urban areas, growth of cities is likely to have other consequences that are as yet underappreciated. To cite an example, from over 14 million m³ of water produced by desalination in the Gulf every day in 2015 [28], the current production capacity of sea water desalination plants drawing water from Gulf is over 20 million m³ per day, which is further expected to rise to 80 million m³ per day by 2050 [29], with huge amounts of hot salt brine wastes being discharged into shallow coastal areas after processing. This projected growth of desalination capacity and consequent increases in brine discharge in the Gulf

are likely to have substantial region-wide impacts on the already extreme temperatures and salinity, further increasing sea temperatures between 0.5°C and 1.4°C and elevating salinity by 10–18 PSU at basin-wide scales by 2050 [28,30]. Considering the fact that the Arabian Gulf is already warming at twice the rate of other regions [14], such stressors are bound to amplify the impacts of climate change. Already many marine organisms in the Gulf are living very close to the margins of their physiological tolerance [31,32].

4. Climate change impacts on reproductive performance

Temperature extremes appear to be the most detrimental factor of climate change, with the gonads as one of the organs most affected by elevated temperatures [33]. Many phases of the fish reproductive cycle, such as gonadal development, spawning, and gonadal regression, are strongly influenced by water temperature [34]. Tropical marine fishes living in a relatively thermal stable environment and close to upper thermal limits are especially vulnerable to increases in SST and higher than optimal temperature can affect oocyte development and maturation; the timing of ovulation and spawning; and egg quality and reproductive physiology in females [4]. Fish biological functions, such as reproduction and growth, generally respond positively to slight increases in environmental temperature but can also degrade when temperatures exceed a species' thermal optimum and fish being poikilotherms, small changes in water temperature can greatly affect physiological processes including reproduction, which is regulated by complex neuroendocrine mechanisms that respond to climatic events, and any anomalous temperature could directly affect the activity of the neuroendocrine system, inhibiting the expression of the genes for the hypothalamic neurohormones and their receptors and the pituitary hormones [35] and fluctuations in ambient temperature directly impacts metabolic rate and reproductive performance [36]. Normally, reproduction in fish, compared with other physiological processes, only occurs in a bounded temperature range, therefore, small changes in water temperature could significantly affect this process [37], with the spawners and embryos as the most temperature-sensitive stages in the life cycle of fish, and spawning fish have a narrower thermal window and are significantly more sensitive to ocean warming. Accordingly, some degree of seasonality in their reproductive activity is displayed by all fish, which is generally interpreted as a mechanism for ensuring that the larvae hatch into a conducive environment that optimizes their chances for survival [1]. In cold, temperate, and subtropical regions, where most fishes are seasonal breeders, the reproductive cycle is mainly driven by cyclic photoperiod and/or temperature [38,39]. However, in tropical and warm subtropical regions, it is mainly temperature, and also rainfall and lunar cycles that trigger reproductive activity which can extend for long periods [40]. Water temperature, thus has a role in fine tuning the reproductive cycle, that is, the precise timing of gamete formation, maturation and spawning, in tropical environments [41]. Reproductive success could likely be at risk under climate change when spawning habitat temperatures exceed the tolerance limit of the most sensitive life stage, forcing captive species to reproduce during a shorter window [42]. There is also the possibility, as some studies done under controlled conditions concluded that, exposure to elevated temperatures could lead to a skewed sex ratio with a higher ratio of males in species with temperature dependent sex determination and in some cases induce masculinization even in species with genetic sex differentiation [43,44,45,46]. The information presented here is not intended to be exhaustive, and readers can refer to the several articles and comprehensive reviews that have been published for more specific details [39,47,48,49,50,51].

Additionally, the role of environmental stress, in particular, abnormally high temperature and its fluctuations, on suppressing the host's immune system have been recognized long back leading to the incidence of disease outbreaks and pathogen transmission during changes in the environment. In the future, aquaculture operations in the tropics are expected to experience higher cumulative mortalities and faster progression of diseases, and this will most likely be exacerbated by climate change leading to varieties of virulent pathogens [52,53].

5. Changing SST pattern in Abu Al Abyad Island brood stock cage area

A record of sea surface temperatures during the winter months (December, January and February) and the hot summer months (June, July, August and September) between 2001 to 2024 in the dredged canal where the near shore cage system for the brood stock is located in Abu Al Abyad Island shows a gradual increase of the minimum and maximum temperatures during the winter as well as the summer months (Figure 1a, b). The average minimum temperature during peak winter (January-February) SST of $16.71 \pm 0.9^\circ\text{C}$ recorded during the years 2001-2004 increased to $18.28 \pm 0.7^\circ\text{C}$ (an increase of 1.57°C) during the period 2020-2024. Similarly, the average maximum summer SST of $34.75 \pm 0.4^\circ\text{C}$ recorded in the years 2001-2004 increased to $36.04 \pm 0.4^\circ\text{C}$ (an increase of 1.3°C) during the period 2020-2024 (Table 1).

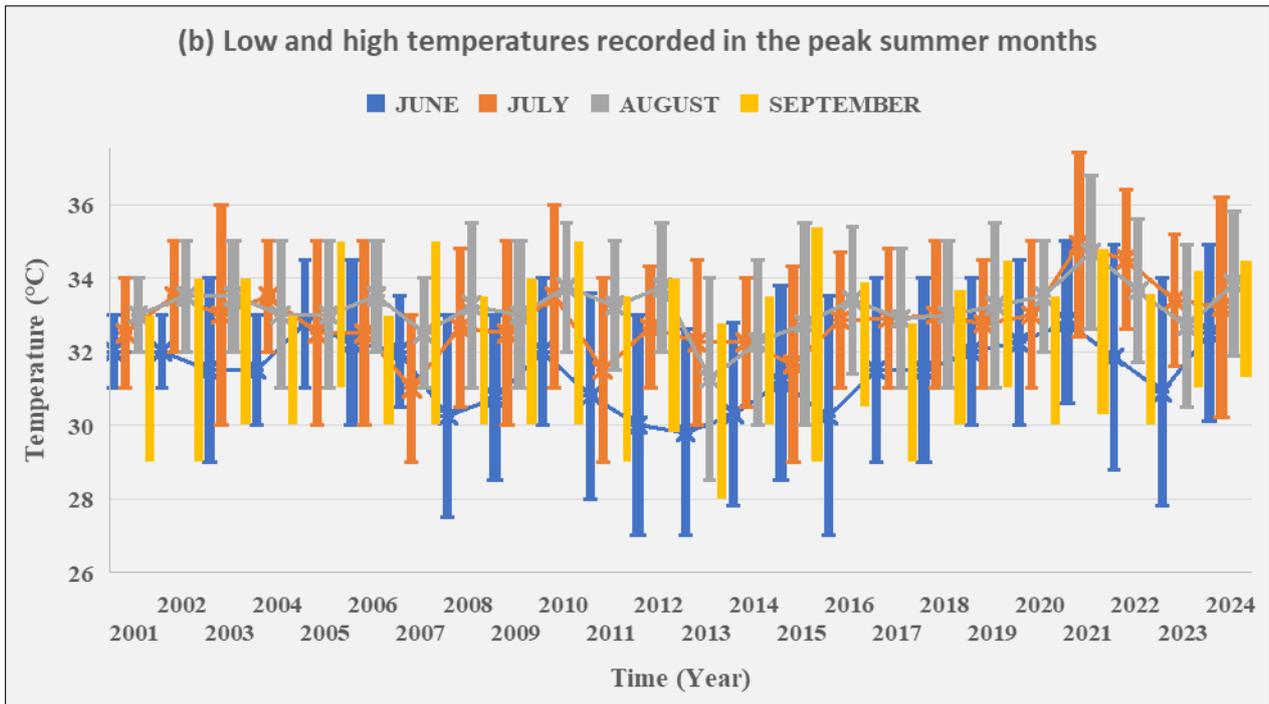
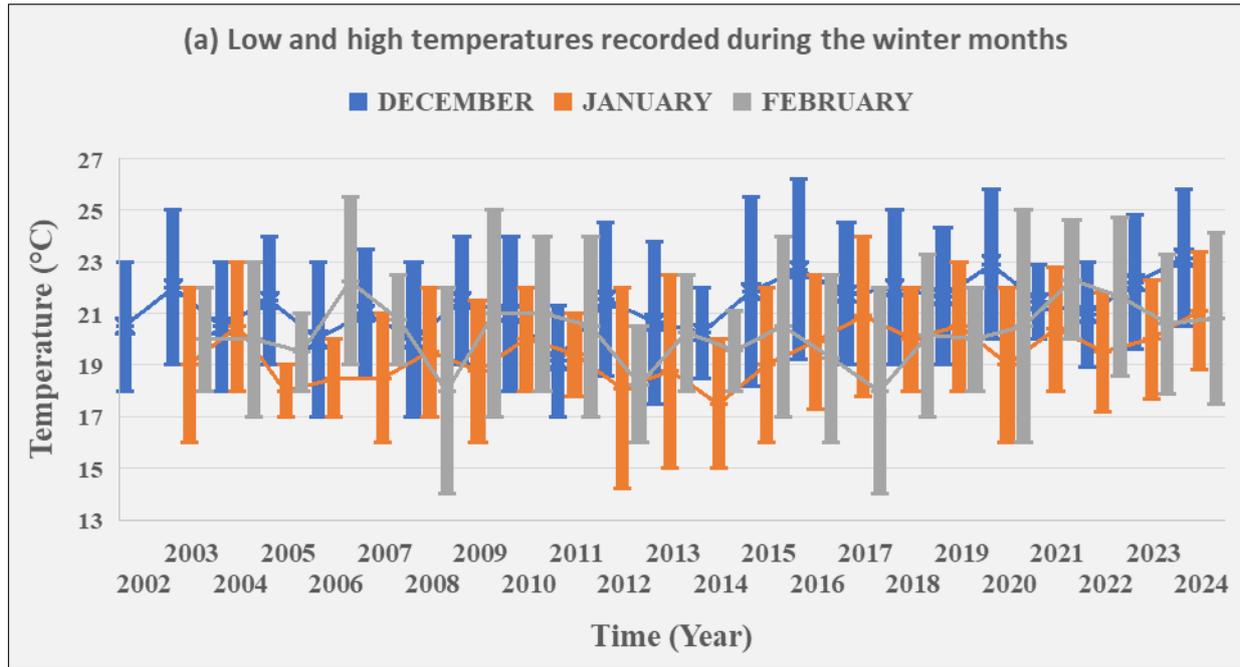


Figure 1 (a) Low and High temperatures in the winter months (b) Low and high temperatures in summer months in the brood stock cage during the years from 2001 to 2024 (the lower end of the bar graph represents the lowest temperature and the upper end the highest temperature recorded for respective months)

Table 1 Sea surface water temperature (SST) difference between 2001-2004 and 2020-2024 during the peak winter and summer periods

Data period	Average Winter (January-February) and summer (July-August) sea surface temperatures (°C) in the fish brood stock cage in Abu Al Abyad Island	
	Low	High
2001 -2004	16.71± 0.96	34.75± 0.47
2021-2024	18.28± 0.73	36.04± 0.73

6. Shortening spawning window in captive fish brood stock in Abu Al Abyad Island

Considering the thermal windows for spawning for each species recorded over the years in the AMSC hatchery, Abu Al Abyad Island, when viable spawning occurs, the optimal thermal regime has been deduced for the three species. From the day first spawning starts, and the day the optimum temperature threshold is crossed, is taken as the active spawning window, when viable spawns could occur. For the winter spawning species, the optimal thermal window is 22.5 to 25.0°C and 18.5-22.5°C for Goldlined seabream (Gabit) and Silver black porgy (Sobaity) respectively. For White-spotted rabbitfish (Safi) which is a spring spawning fish, the optimal thermal window is 23.5 to 27.5°C (Table 2). Usually, a rise in water temperature above the threshold triggers the end of the spawning season. A statistical analysis (one way ANOVA) done on the spawning duration (spawning window) of the three species (Gabit, Sobaity and Safi) for which spawning data are available from the year 2004 to 2024, showed a statistically significant decline in the spawning window ($P < 0.05$) for Gabit and Sobaity, and although not statistically significant, a declining trend in the case of Safi in the duration of the spawning window relative to the changing thermal regime over the years (Figure 2). The reduced spawning window and the termination of the spawning season for the winter spawning seabreams could be attributed to the shortening winter period and early onset of high temperatures in the later years (2021-2024). Although the shortening of the spawning window for the seabreams was related here to changing winter (December-February) temperatures, it is probable that over a longer time frame, temperature shifts may affect the spawning phenology of spring spawning fishes also. In the enclosed channels in Abu Al Abyad with very limited water circulation, where the captive brood stock is held, further temperature pattern shifts and increases can be expected in the coming years pushing the brooders beyond their physiological tolerance limits affecting the maturation and spawning success.

Table 2 Spawning seasons and optimal thermal window for viable spawning in Abu Al Abyad Island

Species	Data period	Season	Months	Temperature (°C)
Gold-lined seabream (Gabit)	2009-2024	Winter	December/January	22.5-25.0
Siler Black porgy (Sobaity)	2004-2024	Winter	December/January/February	18.5-22.5
White-spotted rabbitfish (Safi)	2004-2024	Spring	March/April	23.5-27.5

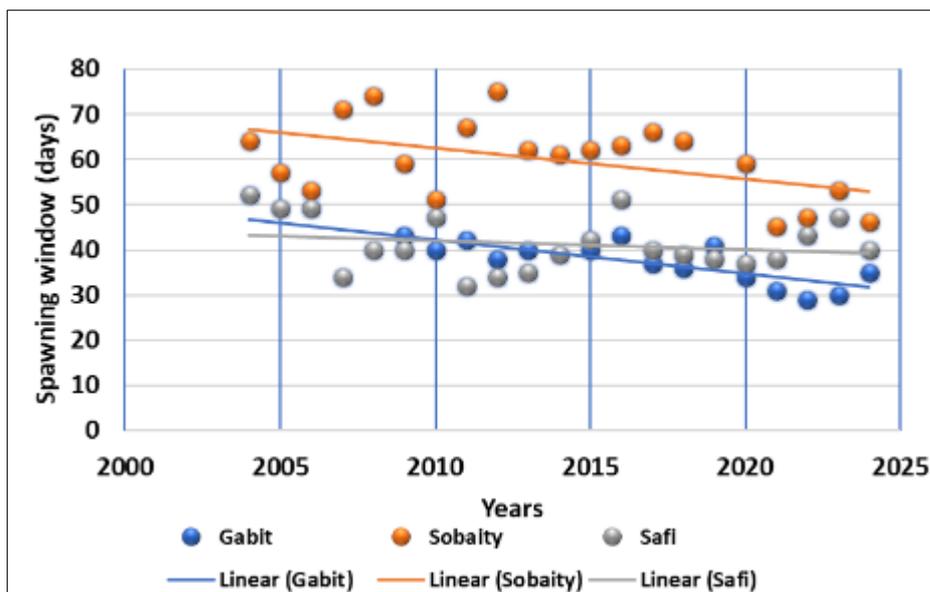


Figure 2 Declining spawning window (days) for the three species over the years

7. Conclusion and recommendations

The world's ocean temperatures and the occurrence of MHWs are increasing at unprecedented rates and is further expected to aggravate the already extreme marine environment of the Arabian Gulf. The observations summarized in this article indicates that fish reproduction and spawning of fish in Abu Al Abyad Island may be directly impacted by further warming of the channel waters and the shortening winters in the coming years. It is plausible that drastic reduction of the spawning season (spawning window) may occur in unusually warmer years, reducing annual reproductive outputs affecting hatchery operations. Developing adaptation and mitigation strategies will be a primary task of a brood stock manager at AMSC, to minimize the negative impacts of these, in order to obtain optimal reproductive performance from the captive held brood fish through appropriate environmental control systems and biological management as outlined below

- Developing climate-controlled RAS brood stock facilities and appropriate supporting technologies to hold the brood stock fish under optimum temperature conditions as required. This will involve substantial capital investments. However, this additional cost could be offset, since the technology will also help in getting out of season egg and larval production.
- By breeding for selective environmental adaptability, brood stock managers can safeguard their operations against the impacts of climate change. Stressor-resistant traits can be genetically selected for, and maintaining adequate population variability can improve resilience and overall fitness to thrive in extreme and harsh environmental conditions.
- Species diversification may or shifting of aquaculture sites could be considered as one of the adaptation strategies, to make the sector more robust to impacts from climate change.
- Developing and implementing better management practices (BMPs) to address aquatic animal health risks specific for brood stock holding systems that are impacted by climate change.
- In addition to these, dietary and nutritional mitigation measures could be a promising option to manage thermal stress. A wide range of studies with a range of supplementary ingredients is required to understand nutritional measures as a mitigation option to combat climate change-induced thermal stress.

Thus, climate change brings in new challenges for aquaculture development and expansion in the UAE. Successful development will largely depend on effective governance and planning tools for selection of species, and location selection, but could also be accelerated through innovations in technology and selective breeding for environmental tolerance, reproductive performance, and disease resistance. Given the growing emphasis on the role of aquatic foods in the current and future transitions to sustainable food systems, streamlining the aquaculture production in UAE to meet food security will require appropriate policies and technologies for promoting sustainable aquaculture under the rapidly changing climate regime.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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