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Impact of Climate Change on Fish Reproduction and Early Developmental Stages

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Abstract: *The reproductive processes of fish and their early developmental stages are profoundly influenced by climate change, particularly through temperature variations and ocean acidification. Seasonal temperature shifts are essential for initiating spawning activities, with cooler temperatures stimulating reproduction in autumn-spawning species and warmer temperatures triggering spring spawners. However, rising global temperatures have been shown to disrupt these cycles, leading to shortened spring spawning periods and delayed autumn spawning. The extent and duration of temperature increases can cause significant reproductive challenges, from altered spawning schedules to complete reproductive failure, especially in species with narrow geographic distributions.*

Furthermore, temperature changes affect the endocrine system by reducing ovarian estrogen production, directly inhibiting reproductive success. Early life stages, such as eggs and larvae, are especially vulnerable to environmental changes, experiencing reduced survival rates, altered development, and disrupted growth patterns. Ocean acidification compounds these effects by impairing larval sensory functions and behavior, disrupting ecological interactions and hindering population replenishment. These combined effects highlight the critical need for understanding and mitigating the impacts of climate change on aquatic ecosystems to preserve biodiversity and maintain ecological balance.

Keywords: Ocean acidification, global temperatures, larval sensory functions, aquatic ecosystems etc

I. INTRODUCTION

Temperature is a critical environmental factor that regulates numerous physiological processes in fish, particularly those associated with reproduction. Key stages such as gametogenesis, maturation, ovulation, spermiation, spawning, embryogenesis, hatching, and subsequent larval and juvenile development are all influenced by temperature. While photoperiod is often considered the primary driver of adult reproductive cycles, temperature plays a vital secondary role in synchronizing the final phases of reproductive maturity and in regulating the duration of reproductive episodes. The effects of temperature are highly seasonal and species-specific. For example, spring and early summer spawners rely on warmer spring temperatures to trigger reproductive maturation. Conversely, elevated temperatures can delay maturation and ovulation in autumn-spawning species. Beyond reproduction, temperature profoundly affects other post-fertilization processes, including embryogenesis and hatching, larval development, growth and survival.

Atlantic salmon (*Salmo salar*) serves as a representative case study of the temperature dependence of fish reproduction. Laboratory studies suggest that this species can tolerate temperatures between 22 and 24.8°C, but its preferred temperature range in marine environments is much narrower, between 4 and 10.8°C. This discrepancy highlights that sublethal temperature changes, which do not elicit acute stress responses in controlled settings, can still have significant ecological implications in natural habitats. Moreover, temperature rarely acts in isolation; its effects can be amplified or mitigated by interactions with other physical and biological factors. For instance, variations in photoperiod can modulate temperature-driven reproductive effects, and nutritional status may influence temperature sensitivity, as seen in tropical damselfish.

The impacts of climate change on fish reproduction are shaped by multiple factors, including latitude, habitat type, water column characteristics, and flow patterns in riverine systems. Climate models predict shifts in seasonal temperature patterns, more frequent temperature extremes, and heightened ocean acidification due to rising atmospheric

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CO_2 levels. In riverine ecosystems, these changes are expected to manifest as increased temperatures, reduced flow rates, and hypoxic conditions. However, the magnitude and nature of these effects are likely to vary regionally.

Marine ecosystems may experience even greater disruptions in reproductive processes due to temperature changes. Variables such as lake inflows, water column stratification, and basin geography will influence the impacts on lacustrine ecosystems. Ocean acidification, driven by increased CO_2 absorption, further compounds these challenges by directly affecting reproductive processes and the early life stages of many marine species. This phenomenon often interacts synergistically with temperature changes, exacerbating their effects.

II. REPRODUCTION

Endocrine Control of Reproduction

The hypothalamic-pituitary-gonadal (HPG) axis is a central mediator of environmental effects on fish reproduction. The hypothalamus produces gonadotropin-releasing hormones (GnRH), which are secreted into synaptic connections in the pituitary gland. These signals stimulate the gonadotropic cells to produce two protein hormones: follicle-stimulating hormone (FSH) and luteinizing hormone (LH). Extensive research, including studies by several scientists, has explored the intricate mechanisms of this axis.

The release of FSH and LH depends on a balance between GnRH stimulation and dopamine inhibition. Dopamine-secreting neurons provide inhibitory regulation, further fine-tuning reproductive processes. Additionally, the pineal gland, which is light-sensitive, secretes melatonin that influences the interaction between GnRH and the pituitary gland. However, the precise mechanisms of melatonin's effects remain unclear. The kisspeptin system also directly modulates GnRH-producing neurons. Gonadal steroid feedback further refines this relationship, with literature emphasizing its significance in regulating reproductive responses to environmental stimuli.

Temperature and the HPG Axis

Temperature plays a critical role in modulating the HPG axis, affecting hormone synthesis, activity, and structure. Many endocrine processes have a baseline temperature below which they cease to function. Within a physiologically acceptable range, rising temperatures enhance hormone synthesis, activity, and metabolism. However, crossing the upper threshold leads to declining hormonal activity.

High temperatures induce structural changes in key reproductive proteins, including FSH, LH, their receptors, and steroid-synthesizing enzymes, reducing their effectiveness. Steroid hormones also become less functional at elevated temperatures due to their increased tendency to form water-soluble conjugates such as sulphates or glucuronides. These conjugates are less effective as they lose solubility and cannot cross cell membranes, limiting interaction with intracellular receptors. Additionally, these conjugates are more readily filtered by the kidneys and excreted in urine, further reducing hormonal availability.

Suppression of Reproduction Due to Temperature

Temperature-induced suppression of reproduction has been documented across a wide range of species, habitats, and thermal ranges, with species-specific differences in temperature sensitivity. Table 1 provides a summary of these thresholds. Notably, temperatures above 30°C suppress reproduction in tropical species, suggesting a common thermal response across taxa, with varying degrees of sensitivity. Cool-water and temperate species often exhibit broader functional ranges compared to tropical species.

Table 1. Temperature Thresholds and Reproductive Effects Across Fish Species

Species	Habitat Type	Temperature Impact (°C)	Effects	References
Arctic charr (*Salvelinus alpinus*)	Cold freshwater	10–11	Inhibition of LH secretion, delayed ovulation	Gillet & Breton, 2009
Atlantic salmon (*Salmo salar*)	Cold anadromous	18	Reduced steroid production, smaller	Pankhurst & King, 2010

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			eggs, lower fertility	
Spiny damselfish (*Acanthochromispolyacanthus*)	Tropical marine	>30	Reduced reproductive output	Donelson et al., 2010
Rainbow trout (*Oncorhynchus mykiss*)	Temperate freshwater	18–21	Lower survival, reduced steroid synthesis	Pankhurst et al., 1996

Mechanisms of Heat Suppression in Temperate Species

Research on temperate species, particularly salmonids, has provided valuable insights into the mechanisms of temperature-induced reproductive suppression. For example, Arctic charr (*Salvelinus alpinus*) exposed to inhibitory temperatures of 10°C showed increased LH secretion and ovulation when treated with synthetic gonadotropin-releasing hormone (GnRHa) combined with the dopamine antagonist pimozide, compared to GnRHa alone. These findings suggest that heightened dopamine inhibition in the pituitary gland may contribute to suppressed ovulation.

In Atlantic salmon (*Salmo salar*), elevated summer and autumn temperatures suppress the steroid-converting enzyme P450 aromatase, reducing the ovary's ability to produce estradiol (E2) from androgen precursors. Consequently, vitellogenin production in the liver is diminished, leading to smaller eggs, reduced fertility, and lower survival rates. Furthermore, high temperatures weaken the binding affinity of hepatic E2 receptors, exacerbating reproductive challenges during vitellogenesis. When vitellogenesis concludes in late autumn, elevated temperatures inhibit the production of the maturational steroid 17,20βP, delaying final oocyte maturation and ovulation. These findings underscore the complex interplay between environmental temperature and reproductive physiology, highlighting the vulnerability of fish species to climate-induced temperature changes.

III. STRESS AND REPRODUCTION

Stress as a Mechanism of Heat Inhibition

The activation of a hormonally mediated stress response is one of the mechanisms through which heat inhibits reproduction in fish. While this mechanism provides an explanation, it does not exclude alternative pathways. Research by many researchers have consistently shown that stress adversely affects fish reproduction. Under stress, a rapid response involving catecholamines increases energy availability and oxygen supply to tissues. This is followed by prolonged activation of the hypothalamic-pituitary-interrenal (HPI) axis, resulting in elevated cortisol levels in teleosts and chondrosteans, as well as 1α-hydroxycorticosterone in elasmobranchs.

Cortisol, though temporarily enhancing energy availability, exerts inhibitory effects on reproduction, growth, and immune function when elevated for extended periods. Its catabolic nature leads to significant long-term repercussions. Stress exposure can rapidly reduce plasma testosterone (T) and estradiol (E2) levels within 15–30 minutes. The mechanisms underlying cortisol's rapid effects on these hormones remain unclear.

Temperature, Stress, and Reproduction

Temperature changes, particularly elevated temperatures, can suppress reproductive processes. While temperature itself is a stressor, noted that in controlled laboratory settings, rising temperatures significantly inhibited reproduction without a corresponding rise in plasma cortisol levels in Atlantic salmon broodstock. This suggests that the HPI axis may not be the sole factor driving reproductive suppression in salmonids.In natural environments, stress responses appear to be less common except under extreme conditions, such as storms or floods, which coincide with environmental disturbances. Evidence of stress reactions across a broad range of environmental conditions remains weak, underscoring the need to differentiate between direct thermal inhibition and stress-induced effects.

Additional Considerations

One critical consequence of elevated temperatures is the inhibition of gonadal aromatase activity, a key enzyme in steroidogenesis. Reduced aromatase activity has two significant reproductive implications related to sex determination and inversion. During early sex differentiation, the suppression of aromatase reduces estrogen production, favoring the development of male phenotypes.Some researchers observed that higher temperatures consistently suppress aromatase, potentially skewing sex ratios towards males. This shift could affect population resilience, although the long-term implications remain poorly understood.

Ocean Acidification and Reproduction

The rising absorption of atmospheric CO_2 by surface oceans leads to ocean acidification, characterized by reduced pH and carbonate ion concentrations. This phenomenon poses significant threats to marine organisms, particularly calcifying species dependent on carbonate ions for shell and skeleton production

Effects of Ocean Acidification on Fish Reproduction

Elevated CO_2 levels (pCO_2) can disrupt acid-base balance and oxygen transport in aquatic species (Portner et al., 2004; Portner and Farrell, 2008). Larval fish, such as red seabream (*Pagrus major*), are more sensitive to acidification caused by CO_2 than similar pH reductions induced by mineral acids. High pCO_2 induces tissue acidosis, impairing protein synthesis, enzyme function, and cellular oxygen transport.

Fish mitigate acidosis through ion excretion via branchial epithelia, with secondary contributions from kidneys and intestines. Despite their sophisticated acid-base regulation, fish may still face reproductive challenges under prolonged acidification. Studies show species-specific differences in responses to high CO_2 levels. For example, the flounder (*Limandayokohamae*) experiences complete cessation of sperm motility under moderate pCO_2 increases, although this effect is absent in other species. Similarly, Baltic cod (*Gadus morhua*) shows no impairment in sperm motility under similar conditions.

Egg and Larval Sensitivity

Fish eggs and larvae demonstrate varying sensitivities to acidification. The lethal concentration for 50% mortality (LC50) typically exceeds 10,000 ppm CO_2. Clownfish (*Amphiprionpercula*) eggs exposed to 1,000 ppm CO_2 exhibited no significant changes in viability or duration. However, pelagic spawners' eggs may face greater vulnerability due to their more variable exposure to environmental pCO_2 compared to benthic spawners.

Aerobic Scope and Reproductive Output

Elevated pCO_2 can reduce aerobic capacity, indirectly impacting reproductive performance. For example, tropical cardinalfish species (*Ostorhinchusdoederleini* and *O. cyanosoma*) exposed to 1,000 ppm CO_2 experienced 33–47% reductions in aerobic capacity, potentially limiting their reproductive potential. Extreme temperatures exacerbate these effects, as seen in sockeye salmon (*Oncorhynchus nerka*), where high water temperatures collapse aerobic scope, preventing successful migration and spawning.

Early Life History Stages

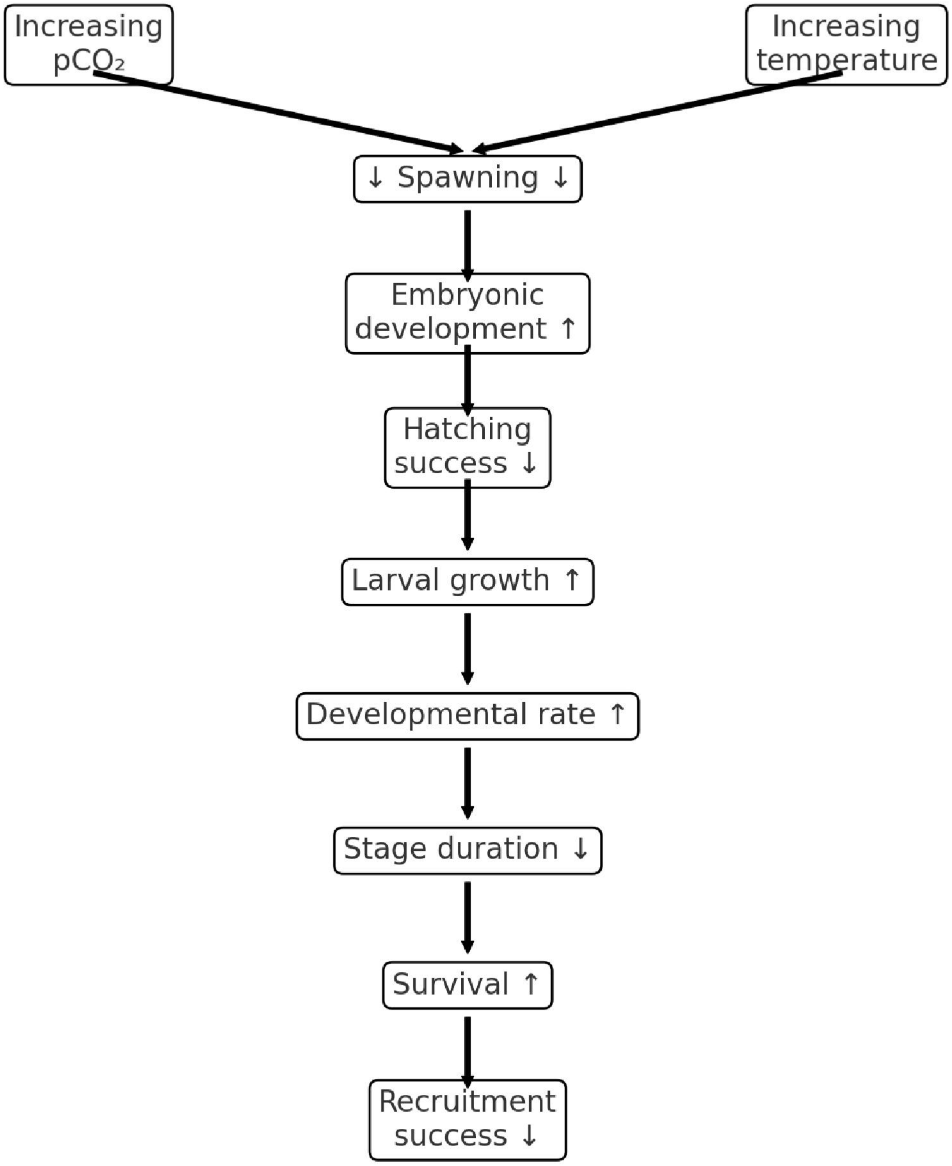
Effects on Egg Incubation

Eggs are among the most temperature-sensitive stages in the life cycle of fish. Many species exhibit narrow thermal tolerances, with deviations of just 6–8°C above or below the optimal spawning temperature resulting in significant mortality. In tropical species, even slight temperature increases can drastically elevate egg mortality rates. The inability of species to adjust their spawning periods to align with optimal temperatures for embryonic development may reduce hatchling survival as global temperatures rise.

For instance, brook trout (*Salvelinus fontinalis*) require a temperature range where gametogenesis is triggered at levels up to 2–8°C lower than those needed for successful egg development. Some species, however, engage in spawning behaviors at suboptimal temperatures, which significantly compromises embryonic survival. Increased mortality has been documented during development in high temperatures, affecting gamete viability and ovulation processes.

Temperature also influences the developmental rate of embryos. Many fish species exhibit a Q10 value of approximately 3, meaning that for every 10°C increase in temperature, the rate of embryonic development more than triples. Consequently, higher temperatures accelerate hatching, shortening incubation periods. While this can range from minutes to hours in smaller eggs, and hours to days in larger eggs, such accelerated timelines can disrupt synchrony with environmental conditions essential for larval survival. Cold-water species with extended incubation periods are especially vulnerable to this mismatch.

Hatching timing is also influenced by external stimuli, such as light cycles, which help ensure larvae emerge under conditions that minimize predation risks. For example, benthic eggs commonly hatch at night when visual predators are less active, enhancing larval survival. Disruptions in temperature-regulated incubation periods could undermine these adaptive strategies, reducing overall reproductive success.



Physiological and ecological responses to increased water temperature and elevated pCO_2 during the early life history of fishes. ↑ = increasing rate, ↓ = decreasing rate.

Acclimation and Adaptation

Fish species demonstrate varying degrees of resilience to thermal challenges, influenced by their thermal history and the environmental variability of their habitats. Some species show evidence of acclimation or adaptation to rising temperatures, offering potential for survival under changing climate conditions.

For example, bullhead populations (*Cottus gobio*) from habitats with narrower annual thermal ranges (4.5–11.5°C) exhibit reduced resilience to high temperatures compared to populations from wider thermal ranges (0.5–19.2°C). Similarly, northern Great Barrier Reef populations of reef fish species perform worse under high temperatures than their southern counterparts, which experience greater thermal variability. These findings suggest that populations from more variable environments may be better equipped to cope with future heat stress.

Laboratory studies further support the role of thermal history in thermal tolerance. Spiny damselfish (*Acanthochromispolyacanthus*) raised at elevated temperatures from birth exhibited better reproductive performance at temperatures exceeding 30.8°C compared to individuals with shorter acclimation periods. Furthermore, offspring from parents acclimated to high temperatures demonstrate enhanced thermal tolerance, suggesting transgenerational acclimatization.

While acute thermal stress often reduces reproductive potential, prolonged exposure to elevated temperatures can drive physiological adaptations that mitigate adverse effects. These findings highlight the importance of understanding species-specific responses to temperature variability when predicting the impacts of climate change on fish populations.

IV. CONCLUSION

The reproductive processes and early life history stages of most fish species are already experiencing significant disruptions due to climate change. These effects manifest across various biological levels, and our understanding of these processes continues to evolve. The ability of fish to respond to thermal challenges depends on numerous factors, including habitat-specific variables, energy reserves, reproductive age, and the intensity and timing of thermal stress.

The interplay between stress, elevated temperatures, and ocean acidification significantly impacts fish reproduction. Stress responses, driven by cortisol, and suppressed aromatase activity disrupt key reproductive pathways, while acidification compounds these effects by impairing larval development and sensory functions. Further research is essential to clarify the long-term consequences of these environmental stressors and their cumulative impacts on fish populations.

Despite advancements in understanding, our ability to predict the consequences of these changes remains limited for most species. This knowledge gap poses challenges for developing effective management strategies to mitigate climate change impacts on fish populations. Increased research efforts are needed to assess species-specific vulnerabilities and adaptive capacities to inform conservation efforts and ensure the long-term stability of aquatic ecosystems.

REFERENCES

[1] Akazome, Y., Kanda, S., Okubo, K., and Oka, Y. (2010). Functional andevolutionary insights into vertebrate kisspeptin systems from studies offish brain. Journal of Fish Biology 76, 161–182. doi:10.1111/J.1095-8649.2009.02496.X

[2] Angilletta, M. J. (2009). ‘Thermal Adaptation: A Theoretical and EmpiricalSynthesis.’ (Oxford University Press: New York.)

[3] J. Cerda´ and E. Lubzens.) pp. 39–76. (Springer: Dordrecht.)Barton, B. A. (1996). General biology of salmonids. In ‘Principlesof Salmonid Aquaculture.’ (Eds W. Pennell and B. A. Barton.)pp. 29–95. (Elsevier: Amsterdam.)

[4] Benoıˆt, H. P., Pepin, P., and Brown, J. A. (2000). Patterns of metamorphicage and length in marine fishes, from individuals to taxa. CanadianJournal of Fisheries and Aquatic Sciences 57, 856–869. doi:10.1139/CJFAS-57-4-856

[5] Bergenius, M. A. J., Meekan, M. G., Robertson, D. R., and McCormick, M. I.(2002). Larval growth predicts the recruitment success of a coral reeffish. Oecologia 131, 521–525. doi:10.1007/S00442-002-0918-4

[6] Blaxter, J. H. S. (1991). The effects of temperature on larval fishes.Netherlands Journal of Zoology 42, 336–357. doi:10.1163/156854291X00379

[7] Brauner, C. J. (2009). Acid–base balance. In ‘Fish Larval Physiology’. (EdsR. N. Finn and B. G. Kapoor.) pp. 185–198. (Science Publishers: Enfield.)

[8] Cheal, A. J., Delean, S., Sweatman, H., and Thompson, A. A. (2007). Spatialsynchrony in coral reef fish populations and the influence of climate.Ecology 88, 158–169.