Temperature, metabolism and fish performance

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***Abstract*—Temperature influences fish performance through its relationship with metabolic demand, consumption and the energy available for activity and growth. Explaining that relationship requires more than associating warm or cool water with a growth outcome. This paper synthesises a fish ectotherm model, research on oxygen consumption and gill area, a review of physiological responses during thermal change, and an aquaponic carp trial. Together, these sources distinguish a proposed causal mechanism from physiological measurements and observations made under changing production conditions. The model links temperature-dependent demand and consumption to energy budgets and performance, but does not provide universal predictions for individual species. Oxygen consumption offers an approximation of metabolic rate, while physiological responses during thermal ramping demonstrate that outcomes depend on the conditions and fish examined. In the carp trial, poorer late-trial growth coincided with water temperatures below 20 °C, but feeding rate also changed, preventing a temperature-specific causal conclusion. The resulting interpretation is conditional: temperature matters because it can alter the balance between energy demand and acquisition, yet its effect on performance must be assessed alongside physiological capacity and competing explanations for observed growth.**

I. Introduction

Temperature, metabolism and fish performance are connected through the balance between what a fish expends and what it can obtain. A fish ectotherm model links temperature-dependent metabolic demand and consumption to energy budgets, activity, growth and fitness [1]. This connection gives temperature a causal role rather than treating it merely as a background condition. It does not, however, imply that a particular temperature produces the same growth response in every fish. The model describes relationships among physiological and behavioural processes, and its predictions remain conditional on those processes. An explanation of performance therefore needs to ask how temperature changes both energy requirements and the capacity to meet them.

Physiological responses complicate any account based on temperature alone. A review of fish responses to hyperoxia discusses cardiorespiratory and biochemical adjustments during thermal ramping and reports species-dependent thermal outcomes [2]. Such evidence is relevant because thermal change can be examined alongside changes in oxygen conditions, rather than being interpreted solely through growth. It also sets a boundary on generalisation: a response observed under elevated oxygen conditions cannot simply be assigned to temperature or extended to all species. The central problem is therefore not whether temperature matters, but how to distinguish its contribution from the other conditions that shape a measured response.

Metabolism requires an operational meaning when physiological observations are compared with performance. An analysis of teleost fishes uses oxygen consumption as an approximation of metabolic rate, includes temperature as a model covariate and examines associations with gill area [3]. Oxygen consumption offers a measurable perspective on metabolic activity, but the measurement is not itself a complete account of growth. This paper first establishes what the available approaches can support, then explains the energy-budget mechanism, compares physiological and growth evidence, and considers the limits of applying that explanation to particular fish and conditions.

II. Background and Scope

The available evidence approaches the relationship between temperature and performance at different levels. The fish ectotherm model connects metabolic demand and consumption to activity, growth and fitness, making its principal contribution an explicit causal framework [1]. The teleost analysis instead relates an approximation of metabolic rate to measured and modelled characteristics, including temperature and gill area [3]. These approaches answer related but different questions: a model can show how changes in demand and consumption might affect an energy budget, whereas an oxygen-consumption analysis examines a physiological correlate. Neither approach, by itself, establishes the growth effect of a particular temperature in an aquaponic population.

A European Carp trial provides a setting in which temperature and growth were both observed. Growth was poorer later in the trial when water temperature was below 20 °C, but feeding rate changed over the same period [4]. This conjunction is informative because realised growth reflects the conditions experienced by fish rather than an isolated physiological variable. It is not a controlled estimate of temperature's contribution: the change in feeding offers another possible explanation for part of the observed change. The temperature observation should therefore be read as context consistent with a possible thermal influence, not as evidence that crossing 20 °C independently caused poorer growth.

The scope of this synthesis is narrower than a species-specific temperature guide. It asks what causal relationship between temperature, metabolism and performance the accepted evidence can justify. The model supplies a mechanism linking demand and consumption to growth [1]; oxygen-consumption work provides a way to examine metabolism without equating it with growth [3]; and the carp trial illustrates why a coincident observation cannot isolate temperature from feeding [4].

The remaining gap is a direct, condition-specific demonstration that separates thermal effects on metabolic requirements, consumption and observed growth in the same fish. This gap limits prediction without negating the underlying mechanism.

III. Core Concepts and Mechanisms

The central mechanism is an energy-budget relationship, not a claim that warming or cooling must always improve performance. In the fish ectotherm model, temperature affects metabolic demand and consumption, and their interaction shapes the energy available for activity and growth [1]. If demand changes without a corresponding capacity to obtain energy, the balance relevant to growth can change; if consumption also changes, the outcome cannot be inferred from demand alone. This reasoning explains why temperature can matter causally while leaving the direction and magnitude of a growth response conditional. The model's conclusions describe the consequences of its assumptions, not measured growth responses for every species.

Oxygen consumption supplies a physiological measure that can help examine one part of this relationship. The teleost study treats oxygen consumption as an approximation of metabolic rate and considers temperature and gill area in its analysis [3]. The reported gill-area associations indicate that anatomical variation belongs in the interpretation of metabolic measurements, rather than attributing every difference among fish to temperature. At the same time, approximating metabolic rate from oxygen use does not directly measure energy intake or the allocation of energy to growth. A credible account of performance must keep these quantities conceptually separate: a metabolic indicator can inform the demand side of the explanation without determining the eventual growth outcome.

Thermal change can also be studied through physiological adjustments rather than a single metabolic measurement. The review of hyperoxia describes cardiorespiratory and biochemical responses during thermal ramping and discusses outcomes that differ among species [2]. These observations show why oxygen conditions and the fish being examined matter when interpreting a thermal response. They do not establish that elevated oxygen has one general effect on performance, nor do they turn a response during a ramp into a prediction for sustained growth. Read alongside the energy-budget model, they identify a constraint on simple explanations: the link from temperature to performance passes through physiological responses whose expression depends on the conditions examined [1].

IV. Evidence Synthesis

The clearest direct support for the principal causal explanation comes from the model's explicit treatment of temperature-dependent demand and consumption. It connects those processes to energy budgets, activity, growth and fitness [1]. Physiological work adds detail without testing that entire chain in a single setting: oxygen consumption approximates metabolic rate in the teleost analysis, while gill area and temperature enter its interpretation [3]. The sources are complementary because one articulates the relationship to performance and the other examines a measurable metabolic correlate. Their combination makes the mechanism more intelligible, but it must not be presented as an experimental demonstration that a specified temperature produces a specified growth rate.

Evidence gathered during thermal ramping adds an important qualification to the model-based account. The hyperoxia review considers cardiorespiratory and biochemical adjustments and reports species-dependent thermal outcomes [2]. A temperature-related change in performance therefore cannot be interpreted without considering which physiological response was examined and under what oxygen conditions. This does not contradict the energy-budget model, which likewise links performance to more than a change in metabolic demand alone [1]. Rather, it clarifies what the model cannot settle without additional observations: whether the relevant fish, under the relevant conditions, can sustain the consumption and physiological responses assumed when performance is inferred.

The carp trial illustrates the distance between a plausible mechanism and an identified cause of observed growth. Its poorer late-trial growth coincided with temperatures below 20 °C, but feeding rate changed concurrently [4]. The model gives a reason to investigate temperature, because thermal effects on demand and consumption can alter the energy budget [1]. It does not remove feeding as a competing explanation in the trial. Nor can species-dependent responses discussed in the hyperoxia review resolve that confounding for these carp [2]. Taken together, the evidence supports a causal framework for interpreting temperature and performance, while the trial supplies a qualified example rather than an isolated measurement of thermal impact.

V. Practical Implications and Limitations

The most useful interpretation of a temperature observation is as a prompt to examine connected physiological and performance measures, not as a complete diagnosis. Oxygen consumption can approximate metabolic rate, but the teleost analysis also considers gill area and temperature, indicating that comparison among fish requires attention to more than a water-temperature reading [3]. Where growth changes, feeding must likewise be considered: the carp trial cannot separate the effect of its cooler late-trial conditions from the concurrent change in feeding rate [4]. These constraints favour a conditional conclusion about temperature's contribution over an unsupported claim that one recorded temperature independently explains a growth result.

Species and experimental conditions further limit transfer of a thermal response from one setting to another. The review of hyperoxia reports physiological adjustments during thermal ramping and species-dependent outcomes [2]. Its evidence can inform questions about the interaction of oxygen conditions and thermal change, but it does not warrant assuming that the same response occurs under other oxygen conditions or over a different period. The ectotherm model similarly explains how demand and consumption could shape performance

without supplying universal species-specific predictions [1]. Applying either source to a particular population therefore requires evidence about that population's metabolic response and realised performance, rather than reliance on a general thermal narrative.

A stronger test of the causal explanation would distinguish temperature's influence from changes in consumption and other conditions that affect the interpretation of growth. The carp trial demonstrates the need for that distinction because its temperature and feeding changes were concurrent [4]. Oxygen-consumption measurements could inform the metabolic component, provided their status as an approximation and the gill-area associations are retained in interpretation [3]. Physiological responses under changing thermal and oxygen conditions would require equally careful specification of species and conditions [2]. These are requirements for validating a proposed explanation, not evidence that a particular temperature or intervention will improve fish performance.

VI. Conclusion

Temperature has scientific significance for fish performance because metabolic demand and consumption jointly determine the energy-budget relationships through which activity and growth can be understood [1]. Oxygen consumption offers a way to examine metabolism, while its interpretation also involves characteristics such as gill area [3]. Physiological responses during thermal change differ with the conditions and species considered [2]. Consequently, the causal explanation is stronger than a simple correlation between water temperature and growth, but it is also more conditional: metabolic response, energy acquisition and realised performance must not be treated as interchangeable observations.

The evidence does not establish a general growth effect for a specified temperature. In the carp trial, poorer late-trial growth coincided with water below 20 °C, yet feeding rate changed at the same time [4]. The highest-value next step for testing this explanation is to examine thermal conditions, consumption, metabolic response and growth together while separating changes that could otherwise explain the result. Until such evidence is available for the fish and conditions of interest, the model and physiological studies support a reasoned interpretation of temperature's role, not a universal prediction of performance [1], [2], [3].

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