pH as a biological and chemical control variable

Grant Kinkead
Independent Researcher, Melbourne, VIC, Australia
grant@kinkead.au

***Abstract*—pH is often treated as a single water-quality measurement, yet its significance lies in the chemical relationships and biological responses that the measurement brings together. In aquatic systems, dissolved carbon dioxide and alkalinity influence pH and its resistance to change. pH, in turn, affects the consequences of ammonia exposure and the conditions experienced by aquatic organisms. Aquaponic systems make these relationships especially clear: nitrification generates acidity, while fish responses and plant nutrient availability depend on the resulting chemical environment. This paper synthesises an aquaculture review of alkalinity and water chemistry with an aquaponics review of interacting biological requirements. It distinguishes pH from buffering capacity, traces the principal pathways linking chemical change to biological effect, and explains why a pH reading cannot independently establish suitable conditions for every organism or system. The evidence supports treating pH as an interpretive control variable whose meaning depends on the processes changing it and the organisms exposed to it. It does not support a universal target or a quantitative prediction across species and systems.**

I. Introduction

The importance of pH in aquatic systems extends beyond whether water is described as acidic or alkaline. Dissolved carbon dioxide, alkalinity and buffering are chemically connected to pH, so a change in the reading may reflect a change in the balance among those conditions. Its biological significance also depends on what else is present: the consequences of ammonia exposure and the activity of phytoplankton are among the processes associated with pH in aquaculture [1]. pH is therefore a chemical indicator with biological consequences, rather than an isolated property that can be interpreted without reference to the surrounding water chemistry.

Aquaponics brings several pH-dependent processes into the same water-quality discussion. Nitrification generates acidity, while fish responses and plant nutrient availability depend on pH-related conditions [2]. A shift in pH can consequently matter to organisms in different ways, even when it arises from a single chemical process. The central difficulty is not simply recognising that pH matters, but explaining how a measured change relates to its cause and to the biological response of interest. The aquaponics evidence also cautions against treating one species or system arrangement as representative of all others [2].

This paper examines pH as a biological and chemical control variable by connecting the processes that shape it with the responses through which it acquires practical meaning. It first distinguishes the pH reading from the buffering conditions that influence its behaviour, then considers dissolved carbon dioxide, nitrification, ammonia, fish responses and plant nutrient availability. The argument is deliberately qualitative. The accepted reviews establish these relationships, but their synthesis does not yield a universal pH target or a transferable numerical account of response across aquatic systems [1], [2].

II. Background and Scope

An aquaculture account of pH begins with the chemistry of the water, particularly the relationship between dissolved carbon dioxide, alkalinity and buffering [1]. An aquaponics account places that chemistry alongside acidity produced by nitrification and the differing responses of fish and plants [2]. These approaches are complementary rather than competing. The first helps explain why pH changes or resists change; the second shows why its consequences cannot be assessed for a single biological component alone. Together, they support an explanation that moves from chemical cause to biological consequence without treating the pH reading as a complete description of water quality.

pH and alkalinity answer different questions. A pH measurement describes the present acid-base condition, whereas alkalinity is relevant to how the water buffers changes in that condition [1]. Two observations of pH may therefore require different interpretations if the surrounding buffering conditions differ. Conversely, knowing that water has buffering capacity does not by itself describe the present pH or the response of organisms to it. This distinction matters when interpreting acidity generated within an aquaponic system: the chemical effect of nitrification has to be understood in relation to the water in which it occurs [1], [2].

The scope here is causal interpretation, not the selection of an operating set point. Boyd and colleagues connect pH-related chemistry to ammonia and phytoplankton in aquaculture, while Lobanov and colleagues describe pH-dependent fish responses and plant nutrient availability in aquaponics [1], [2]. These accounts establish several pathways by which pH matters, but they do not make those pathways interchangeable. A chemical change relevant to ammonia cannot simply stand in for evidence about a particular fish response, and a plant nutrient response cannot establish a universal condition for fish. The remaining task is to explain these links together while retaining their distinct evidence boundaries.

III. Core Concepts and Mechanisms

The chemical control role of pH is most apparent when it is considered with dissolved carbon dioxide and alkalinity. Changes in dissolved carbon dioxide are linked to changes in pH, while alkalinity contributes to buffering against acid-base

change [1]. A pH reading thus reports a condition shaped by interacting chemical processes; it does not identify which process produced that condition. This matters because an observed change may call for an explanation of the water's carbon dioxide and buffering context, not merely a description of the new reading. The review evidence supports this relationship, but not a quantitative prediction for an unspecified system.

Nitrification provides a biological process that can alter that chemical condition. In aquaponics, it generates acidity, creating a direct link between biological activity and the pH environment experienced by fish and plants [2]. Buffering is relevant because the same acid-generating process must be interpreted against the water's capacity to resist pH change [1]. These linked processes explain why pH functions as a control variable in a living system: it reflects a chemical consequence of biological activity while also helping describe the conditions under which other biological responses occur. The sources establish the direction of this causal connection, not a fixed rate or magnitude of change.

The biological meaning of pH is pathway-specific. In aquaculture, its relationship with ammonia affects the significance of ammonia exposure, and pH is also connected with phytoplankton activity [1]. In aquaponics, fish responses and plant nutrient availability add further pH-dependent considerations [2]. These are not four measurements of a single biological effect. Rather, they show that a shared chemical condition can intersect with distinct processes and organisms. The implication is that pH becomes informative when paired with the particular exposure or response being considered; on its own, it cannot establish the condition of every biological component.

IV. Evidence Synthesis

The two reviews converge on a causal sequence without describing identical systems. Dissolved carbon dioxide and alkalinity help explain the chemical setting in which pH is measured, while nitrification supplies a documented source of acidity in aquaponics [1], [2]. This sequence connects an observed state to processes capable of changing it. Its strength is explanatory: it prevents pH from being interpreted as though the reading arose independently of the water's chemistry or biological activity. Its limit is equally important. Establishing these relationships does not identify the dominant cause of a particular observation without evidence about the conditions of that system.

The biological evidence gives the chemical account its significance. A pH change can alter how ammonia is understood in aquaculture, while pH-dependent fish responses and plant nutrient availability make the condition relevant to different parts of an aquaponic system [1], [2]. The sources therefore support a connected interpretation: chemical processes shape pH, and pH helps determine the context in which biological effects arise. They do not justify collapsing those effects into a single measure of system suitability. The response of one organism or process remains an incomplete basis for judging another, even when both are exposed to the same water.

The distinction between a relationship and a prediction is central to this synthesis. The accepted evidence identifies connections among carbon dioxide, buffering, pH, nitrification and biological responses [1], [2]. It does not, in the supplied claim support, establish a common numerical threshold at which those responses become equivalent across species or system arrangements. The aquaponics review's caution about species and system dependence reinforces that limit [2]. pH is therefore well supported as a variable for explaining interactions, but a particular reading cannot be assigned a universal biological interpretation from these reviews alone.

V. Practical Implications and Limitations

Interpreting pH responsibly requires separating the observation from its possible causes. A change in the reading may be considered alongside dissolved carbon dioxide and buffering because those chemical relationships influence how pH behaves [1]. In an aquaponic setting, acidity generated by nitrification is another relevant part of the explanation [2]. This is an interpretive principle, not a claim that any one process caused a specific observed change. Its practical value lies in avoiding an unsupported inference from a single measurement. Establishing the cause in a particular system would require evidence about that system's accompanying chemical and biological conditions.

A second implication is that biological interpretation must specify whose response is at issue. pH bears on ammonia-related consequences and phytoplankton activity in aquaculture, while aquaponics evidence identifies fish responses and plant nutrient availability as further considerations [1], [2]. These relationships make pH important, but they also expose a trade-off in reasoning: a condition discussed in relation to one response cannot automatically be described as suitable for every other response. Species and system dependence place limits on generalisation [2]. The supported conclusion is that biological meaning is conditional, not that the sources establish a single preferred condition.

The principal evidence gap for this paper is quantitative and system-specific. The mapped claims support the main causal explanation, including carbon dioxide and buffering relationships, nitrification acidity, and several pH-dependent biological effects [1], [2]. They do not supply a validated basis here for predicting the size of those effects in an individual aquaponic system or for specifying a universal threshold. Testing a more particular interpretation would require observations of the relevant chemical conditions and the biological response being assessed. Until then, the defensible use of pH is as part of a causal account, with its limits stated rather than concealed.

VI. Conclusion

pH is a biological and chemical control variable because it connects the changing chemistry of aquatic water with consequences for living organisms. Dissolved carbon dioxide and alkalinity shape its chemical context; nitrification can generate acidity; and ammonia-related consequences, fish responses, phytoplankton activity and plant nutrient availability

give the resulting condition biological significance [1], [2]. These connections explain why pH deserves attention, but also why the reading cannot serve as a complete judgement of a living system. Its meaning depends on the process changing it and the response under consideration.

The strongest next step for any more specific claim is to connect pH observations with evidence about the relevant water chemistry and organism or process, rather than extrapolating a universal interpretation from the reviews. The accepted evidence supports a coherent causal framework, not a common numerical target across species and systems [1], [2]. Treating that distinction as a substantive scientific limit preserves the usefulness of pH: it remains a concise indicator, while the explanation of what it indicates stays grounded in the chemical and biological conditions that give it meaning.

ACKNOWLEDGMENT

The author used artificial intelligence tools to assist with manuscript drafting and revision, and with LaTeX and bibliography preparation. The author reviewed all AI-assisted output and remains responsible for the final content.

REFERENCES

[1] C. E. Boyd, C. S. Tucker, and B. Somridhivej, "Alkalinity and hardness: Critical but elusive concepts in aquaculture," *Journal of the World Aquaculture Society*, 2016.

[2] V. Lobanov, H. Monsees, F. Latrille, G. Pate, and A. Joyce, "Coupled vs. decoupled aquaponics: Evidence, mechanisms, and methodological gaps in the productivity hypothesis," *Aquacultural Engineering*, 2026.