Dynamic balance, lag and system adjustment

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***Abstract*—Dynamic balance in aquaponics concerns the relationship between ammonia entering the water and the capacity of microbial communities to transform it. That relationship can change as a biofilter establishes or as ammonia availability changes, but the available evidence does not justify treating nitrifying capacity as an immediate response to a new load. An aquaponics study identifies aerobic compartments with nitrifying biofilter activity, while a marine recirculating aquaculture case study documents nitrifier development over weeks without demonstrating full maturation after 17 weeks. Laboratory experiments provide more direct evidence of lag: an enriched nitrifying culture produced nitrate later and nitrified more slowly when ammonium became available after starvation. These studies support a cautious account of dynamic balance as a changing relationship between loading and microbial response. They do not establish the rate at which an established aquaponic biofilter adapts to sustained higher ammonia loading, or quantify its response to an abrupt increase. System adjustment should therefore be understood as a process that may require time, with its magnitude and duration dependent on conditions that require direct measurement.**

I. Introduction

Dynamic balance in aquaponic nitrification is not simply the presence of bacteria capable of transforming ammonia. It also concerns whether their activity at a particular time corresponds to the ammonia becoming available. The importance of that timing is evident in experiments with an enriched nitrifying culture: after ammonium starvation, renewed availability was followed by delayed nitrate production and lower nitrification rates than in non-starved cells [1]. This is direct evidence that a microbial response can lag behind a change in substrate availability. Because the experiments used an enriched laboratory culture, however, their observed recovery cannot be assumed to describe the timing or magnitude of a complete aquaponic system's response.

The development of nitrifying capacity presents a related, but distinct, timing problem. In a marine recirculating aquaculture case study, nitrifiers developed in new biofilters over weeks, yet full maturation or maximum capacity had not been demonstrated by week 17 [2]. Establishment over time is consistent with the need to distinguish an operating biofilter from one whose capacity has been established under its prevailing conditions. It does not, by itself, show how an established biofilter responds when ammonia loading rises suddenly. The distinction matters because slow initial establishment and delayed adjustment after a load change are different observations, even if both caution against assuming an instantaneous microbial response.

Within aquaponics, aerobic compartments have been described as nitrifying biofilters, and differences among measured nitrogen species were interpreted as consistent with some nitrification [3]. This locates the microbial process within a system that also contains fish and plant compartments, but the study did not test adaptation to sustained ammonia loading or lag following an abrupt load change. This paper therefore develops a bounded explanation of dynamic balance, lag and system adjustment. It first distinguishes the kinds of evidence available, then relates biofilter establishment and recovery after starvation to the proposed causal account, and finally identifies what remains unverified in aquaponic operation.

II. Background and Scope

The evidence approaches nitrification at different levels. The aquaponics compartment study associates microbial community profiles and water conditions with activity consistent with nitrification in aerobic parts of a functioning system [3]. A review addresses microbial maturation and factors that may constrain nitrification in aquaponics, but reports neither an established direct causal relationship between maturation and improved production nor a demonstration of nitrifier lag after abrupt load changes [4]. Together, these works establish the relevance of microbial activity and maturation without measuring the specific adjustment sought here. In particular, detecting conditions compatible with nitrification is not equivalent to measuring the capacity available to process a newly increased ammonia load.

Longitudinal observation provides a different perspective. The marine recirculating aquaculture case study followed nitrifier succession and water quality in two new biofilters with sharply different stocking densities after a fish mortality event [2]. Nitrifiers developed over weeks, but full maturation was not demonstrated within the 17-week observation. The contrast in stocking density is informative about the circumstances under which establishment was observed, not a controlled test of the effect of ammonia loading. Other differences, including oxidative-agent use, confounded the comparison, and nitrification rates were not directly measured. The study therefore supports a claim about prolonged establishment more securely than a claim about load-dependent adjustment.

Recovery experiments address a narrower causal question more directly. In duplicate tests of an enriched nitrifying culture, a period without ammonium was followed by delayed nitrate production and reduced nitrification rates when ammonium became available again [1]. That sequence links a change in substrate history to a measurable lag in response. It

differs from both initial biofilter establishment and an abrupt increase imposed on an already active aquaponic biofilter. The scope of the present synthesis is consequently limited: it can explain why current nitrifying activity and future capacity should not be treated as interchangeable, but it cannot specify an aquaponic adjustment time or prove that sustained higher loading produces a particular gain in capacity.

III. Core Concepts and Mechanisms

Dynamic balance is best understood here as a time-dependent relationship between ammonia availability and microbial transformation, rather than as a fixed property of an aquaponic system. Aerobic aquaponic compartments show evidence consistent with nitrifying biofilter activity [3], while newly activated marine biofilters show that nitrifier establishment can extend over weeks [2]. These observations support the distinction between a process being present and its capacity having developed sufficiently for a particular load. They do not establish a universal threshold for balance. The implication is conceptual but important: an observation of nitrification at one point in time cannot, without a capacity measurement, establish how the system would perform under a different loading condition.

Lag describes the interval or delayed response between a change in ammonia availability and the corresponding nitrification outcome. Its clearest support in the accepted evidence comes from the enriched culture after ammonium starvation, where nitrate production was delayed and nitrification rates were lower on recovery [1]. This result shows that resumed substrate availability need not restore the previous response immediately. It does not show that every increase in ammonia availability has the same effect: a starved culture recovering activity differs from an established biofilter receiving a higher load. The mechanism supported by this experiment is a dependence of observed nitrification on the culture's recent substrate history, not a quantified rule for aquaponic load changes.

System adjustment includes the development or recovery of microbial activity as conditions change, but those forms of adjustment must remain separate in the causal account. The marine biofilters provide evidence of establishment without demonstrated maximum capacity [2]; the enriched culture provides evidence of delayed recovery after starvation [1]; the aquaponics study identifies compartments where nitrification is plausible without testing either transition [3]. Taken together, the studies make it reasonable to question whether available capacity will immediately match a changed ammonia input. They do not demonstrate how much capacity increases under sustained loading, how quickly such an increase occurs, or whether the same response applies across the differing systems studied.

IV. Evidence Synthesis

The strongest direct evidence for lag is experimental, but it concerns recovery from deprivation rather than a sudden increase above an established load. In the enriched culture, ammonium starvation preceded delayed nitrate production and lower nitrification rates on renewed availability [1]. The aquaponics compartment study supplies the system context in which nitrifying activity matters, yet its nitrogen-species patterns do not resolve response time [3]. A review's discussion of maturation and constraints likewise does not demonstrate lag after an abrupt change [4]. These findings fit a cautious causal explanation: nitrification can be present while its response to altered availability remains unsettled. They cannot be combined into a measured aquaponic recovery curve.

Evidence for adjustment under continuing load is more indirect. Nitrifier succession in the marine biofilters shows development during an extended period of operation, without demonstrated full maturation by week 17 [2]. That observation is compatible with changing microbial capacity, but the study did not directly measure nitrification rates and its stocking-density comparison was confounded. The aquaponics study's identification of aerobic nitrifying compartments [3] and the review's treatment of microbial maturation [4] add context rather than a controlled test of sustained loading. It would therefore overstate the evidence to claim that a specified increase in ammonia input reliably produces a specified increase in aquaponic nitrifying capacity.

The distinction between an observed nitrogen pattern and a tested response is central to interpreting dynamic balance. Differences among nitrogen species in aquaponic compartments were interpreted as consistent with some nitrification, but cannot establish the rate at which capacity changes [3]. Conversely, delayed nitrate production in a laboratory culture identifies a response to prior starvation without establishing the behaviour of a mixed aquaponic biofilter [1]. The review also cautions against extending microbial maturation directly to improved production outcomes [4]. Across these sources, the evidence supports a temporal explanation of nitrification while leaving the connection between a particular load change, biofilter response and wider system outcome open.

V. Practical Implications and Limitations

The principal practical implication is interpretive: evidence that nitrification is occurring should not be read as proof of spare capacity or immediate adjustment to a higher load. Aquaponic aerobic compartments can exhibit activity consistent with nitrification [3], while the prolonged establishment observed in new marine biofilters shows that development of the relevant microbial community need not be complete early in operation [2]. Neither study directly tests the response of an established aquaponic biofilter to a step change in ammonia input. Accordingly, the evidence supports caution in describing system balance, not a specific loading rule, adjustment interval or predicted water-quality outcome.

The studies also place limits on transferring conclusions between settings. The marine case study involved newly activated biofilters, an observational contrast in stocking density and other confounding differences; it did not directly measure nitrification rates [2]. The aquaponics compartment study characterised conditions and microbial profiles rather than

imposing a loading change [3]. The enriched-culture experiment isolated recovery after ammonium starvation, which is not equivalent to operation of a full aquaponic system under a sustained higher input [1]. These differences explain why the sources can jointly motivate a concern about lag without supplying a single generalisable estimate of its duration or effect.

A direct test of the central adjustment claim would need to distinguish baseline nitrifying activity from the response following a documented change in ammonia loading. Repeated measurements of transformation over time would be necessary to identify a lag or a sustained change in capacity, rather than inferring either from community presence or a single nitrogen-species pattern. This validation need follows from the absence of direct rate measurements in the marine comparison [2], the observational scope of the aquaponics study [3], and the review's unresolved causal links between maturation and wider outcomes [4]. Such a test would address a gap in the present evidence; its result should not be presumed.

VI. Conclusion

Dynamic balance in aquaponic nitrification describes a relationship that can change with microbial establishment and ammonia availability, not proof that capacity always matches demand. The available aquaponic evidence identifies compartments with activity consistent with nitrification [3]. A marine biofilter case study shows development over weeks without demonstrated full maturation by week 17 [2], while enriched-culture experiments demonstrate delayed recovery after ammonium starvation [1]. Together, these findings support taking lag seriously as a possible feature of system adjustment, but they do not directly establish the response to an abrupt increase in loading within an established aquaponic system.

The highest-value next step is a direct, time-resolved assessment of nitrification before and after a defined loading change in aquaponics. It would test whether capacity changes under sustained higher ammonia availability and whether any delay resembles the recovery observed after starvation, without assuming that the two situations are equivalent [1]. Until that evidence exists, microbial maturation, observed nitrification and adjustment to a new load should be described as related but distinct propositions [2], [3], [4].

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References

[1] L. Abbaszadeh, E. Koutra, K. Tsigkou, M. Gaspari, and P. G. Kougias, "Nitrification upon nitrogen starvation and recovery: Effect of stress period, substrate concentration and ph on ammonia oxidizers' performance," *Fermentation*, 2022.

[2] I. Roalkvam, K. Drønen, H. Dahle, and H. I. Wergeland, "A case study of biofilter activation and microbial nitrification in a marine recirculation aquaculture system for rearing atlantic salmon (salmo salar l.)," *Aquaculture Research*, 2021.

[3] Z. Schmautz, "Environmental parameters and microbial community profiles as indication towards microbial activities and diversity in aquaponic system compartments," *BMC Microbiology*, 2020.

[4] 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.