Stability, resilience and carrying capacity

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

***Abstract*—Aquaponic systems connect fish production, biological filtration and plant growth through shared water and nutrient flows. Their performance therefore depends on relationships among nutrient loading, plant demand, filtration and water quality, rather than on the adequacy of any component considered alone. This paper distinguishes three related concepts. Stability concerns the maintenance of suitable operating conditions over time; resilience concerns the response to, and recovery from, a disturbance; and carrying capacity concerns the loading that a particular system can support without losing acceptable function. Aquaponics reviews support a causal account centred on matching fish-derived nutrient inputs with plant uptake and filtration capacity. Aquaculture evidence adds a specific water-quality mechanism: nitrogen transformations can consume alkalinity and weaken pH buffering. The available synthesis does not, however, establish a universal carrying-capacity threshold or demonstrate that a particular system configuration is consistently more resilient. The most defensible interpretation is conditional: capacity and stability depend on component sizing and operating conditions, while resilience requires direct evidence of system behaviour following disturbance. These distinctions provide a basis for interpreting system performance without treating a productive operating state as proof of recovery capacity.**

I. Introduction

An aquaponic system links fish-derived nutrient inputs to biological filtration and plant uptake. The relationship is consequential because stocking and feeding affect the material entering the water, while filtration, plant demand and system design affect what can be transformed or removed. A system may function satisfactorily at one loading yet experience a deterioration in water quality when that relationship changes. Stability and carrying capacity must therefore be understood through interactions among components, not as fixed properties of a fish tank or plant-growing area in isolation [1]. This paper examines those interactions and distinguishes sustained function from the separate question of how a system responds when disturbed [2].

The three terms answer different questions. Stability asks whether conditions remain suitable during ordinary operation; carrying capacity asks how much loading those conditions can accommodate; resilience asks what happens after a disruptive change. Reviews of aquaponic configurations examine fish, plant and filter sizing alongside nutrient loading, water exchange and operating conditions, but also identify limitations in attributing outcomes to any single configuration [3]. Consequently, satisfactory performance at an observed loading is evidence about that operating state, not proof of an unrestricted capacity or a rapid recovery from disturbance. The discussion first establishes the system boundary, then explains the supported mechanisms, compares their implications and identifies where direct evidence remains necessary [4].

II. Background and Scope

The relevant system boundary encompasses nutrient inputs from fish production, the processes represented by filtration, plant nutrient demand and the shared water in which operating conditions are expressed. An aquaponics review relates performance to the alignment of these elements and identifies stocking, filtration, water quality and design as consequential variables [1]. Another examines how sizing, loading, water exchange and operating conditions vary across systems [3]. These accounts support a system-level explanation, but not the assumption that all designs have the same limiting factor. The boundary adopted here is functional: it includes the relationships needed to explain continuing operation, without treating broader claims about other cultivation systems as evidence of aquaponic performance [5].

The literature contributes different kinds of support to this explanation. Aquaponics reviews address the linked fish, plant and filtration arrangement directly [1], [3]; an aquaculture review explains a narrower chemical relationship between alkalinity, nitrogen transformations and pH buffering [6]. The narrower mechanism helps explain one route by which water-quality stability can change, but it cannot by itself establish the carrying capacity or resilience of a complete aquaponic system. The remaining explanatory challenge is to keep these levels of inference separate. A demonstrated relationship within water chemistry can inform the account of a coupled system without becoming a general prediction of its maximum loading or recovery after disruption [7].

III. Core Concepts and Mechanisms

Stability denotes the persistence of suitable conditions despite the variations encountered during operation. In aquaponics, one plausible basis for such persistence is a workable relationship between fish-derived nutrient loading, filtration and plant demand. If inputs change without a corresponding ability to process or take up nutrients, the balance on which performance depends may no longer hold [1]. This is a causal description rather than a claim that every water-quality variable remains constant. It also shows why stability cannot be inferred solely from plant growth or fish production at a single point in time: each reflects an outcome under particular loading and operating conditions, not the full range over which the linked system can continue to function [8].

Water chemistry supplies a more specific example of a stability mechanism. Alkalinity provides buffering against changes in pH, while nitrogen transformations can consume alkalinity over time [6]. Thus, continuing nitrogen processing and continuing pH stability are not independent assumptions; the chemical capacity that moderates pH can itself change as the system operates. This mechanism helps explain why a condition that appears acceptable at one observation may not remain so under sustained loading. The cited aquaculture analysis does not establish how rapidly an individual aquaponic system would change, or whether it would recover after a disturbance. Those questions require evidence at the level of the system and operating conditions under consideration [9].

Carrying capacity is best treated here as a conditional limit on supported loading, rather than as a universal number. Matching nutrient production with plant demand matters, but stocking, filtration, water quality and design also shape the relationship between inputs and acceptable function [1]. Reviews that compare fish, plant and filter sizing further show why changing one component need not yield a predictable gain if other constraints remain [3]. In this sense, the capacity of a particular arrangement is not established by the nominal size of any single component. It must be interpreted relative to its configuration and operating conditions, with the limiting relationship identified rather than presumed [10].

IV. Evidence Synthesis

Taken together, the aquaponics reviews place loading and component matching at the centre of the stability explanation. Nutrients derived from fish production create an input that must be considered alongside plant demand and filtration; sizing and operating choices affect how those relationships are expressed [1], [3]. The resulting account is stronger than a simple assertion that greater plant area or greater filtration always improves performance. It explains why an increase in one form of capacity may have little value when another component or water-quality condition becomes limiting. It does not, however, provide a single transferable loading threshold: the reported relationships are contingent on how a particular system is arranged and operated [11].

The alkalinity mechanism clarifies how an apparent balance can become less secure over time. Nitrogen transformations may continue while consuming a buffer that helps moderate pH, so the ability to sustain a suitable water environment cannot be judged only from the presence of nutrient processing [6]. This chemical account complements, rather than replaces, the system-level finding that water quality and filtration matter to aquaponic performance [1]. Its implication is analytical: sustained function depends both on handling material flows and on maintaining conditions compatible with that handling. Neither review supplies a universal rate of buffer depletion for aquaponic systems, so the mechanism should not be converted into an unsupported time-to-failure prediction [12].

Resilience requires an additional evidentiary step beyond evidence of stable operation. A system may perform adequately under its observed conditions without having demonstrated that it can withstand a disruption or regain suitable function afterwards. The aquaponics review comparing coupled and decoupled configurations does not find a consistent configuration advantage and identifies limitations in the causal evidence [3]. That finding rules out a simple inference that one arrangement is inherently more resilient. It also distinguishes a defensible conceptual statement from a demonstrated result: component matching may provide room for continued function under a change in loading, but the extent of disturbance tolerance and subsequent recovery cannot be specified from the accepted evidence [13].

V. Practical Implications and Limitations

A useful interpretation of system performance begins with the relationships among loading, plant demand, filtration and water quality, rather than with a single production outcome. The aquaponics evidence connects those relationships to stocking and system design [1], while the comparative review shows that operating conditions and water exchange complicate attribution of an outcome to configuration alone [3]. Accordingly, a claim that a particular arrangement has greater carrying capacity would need to specify the loading and conditions under which acceptable function was maintained. Without that specification, the claim could mistake the consequences of different operating choices for an intrinsic advantage of the arrangement.

The distinction between stability and resilience also affects how evidence should be read. Repeated suitable conditions during routine operation would bear on stability, whereas a resilience claim would need observations spanning a defined disturbance and the subsequent response. The available aquaponics synthesis identifies causal-evidence limits when configurations are compared and offers no consistent advantage that could substitute for such observations [3]. Alkalinity illustrates a further complication: because nitrogen transformations can draw down pH-buffering capacity, an initially suitable water state need not describe the system's continuing ability to absorb change [6]. These points identify what a convincing comparison must demonstrate; they do not establish a particular disturbance tolerance.

The conclusions must remain confined to aquaponic evidence where aquaponic performance is at issue. A review of controlled-environment crop systems describes context-dependent performance and the importance of operating conditions, but its broader scope does not establish the carrying capacity or resilience of a fish, plant and filter system [14]. Within aquaponics, the direct reviews support qualitative links among sizing, loading, filtration and outcomes, yet caution against a configuration-wide ranking [1], [3]. Further validation would therefore be most informative when it records comparable loading and operating conditions, the conditions regarded as suitable, and system behaviour after a specified disruption. Until then, capacity and resilience are conditional interpretations, not universal ratings.

VI. Conclusion

Stability, resilience and carrying capacity describe related but non-interchangeable aspects of an aquaponic system. Stability concerns continued suitable operation; carrying capacity concerns the loading supported under specified conditions; resilience concerns behaviour when those conditions are disturbed. The strongest direct explanation links fish-derived nutrient loading with plant demand, filtration, water quality and system design [1], [3]. Alkalinity and its consumption during nitrogen transformations provide a specific reason that water-quality stability may change during operation [6]. None of these relationships makes a single observed production outcome sufficient evidence for all three concepts.

The highest-value next step is a comparison that distinguishes ordinary operating variation from a defined disruption while documenting loading, component sizing and water-quality conditions. Such evidence could test both the limits of continued function and the course of recovery without attributing differences prematurely to system configuration [3]. For now, the scientifically defensible conclusion is bounded: matching system inputs with processing and uptake helps explain stable operation and conditional capacity, whereas resilience remains a separate property that must be demonstrated through response and recovery evidence [1], [3].

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] M. Krastanova, I. Sirakov, S. Ivanova-Kirilova, D. Yarkov, and P. Orozova, "Aquaponic systems: biological and technological parameters," *Biotechnology & Biotechnological Equipment*, 2022.

[2] T. Zhou, B. Song, T. Liu, Y. Shen, L. Dong, S. Jing, C. Xie, and J. Liu, "Phytochrome f plays critical roles in potato photoperiodic tuberization," *The Plant Journal*, 2019.

[3] 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.

[4] I. Szekely and M. H. Jijakli, "Bioponics as a promising approach to sustainable agriculture: A review of the main methods for producing organic nutrient solution for hydroponics," *Water*, 2022.

[5] A. Tuxun, Y. Xiang, Y. Shao, J. E. Son, M. Yamada, S. Yamada, K. Tagawa, B. Baiyin, and Q. Yang, "Soilless cultivation: Precise nutrient provision and growth environment regulation under different substrates," *Plants*, 2025.

[6] 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.

[7] B. Pragg, M. M. T. Lakshani, T. K. K. C. Deepagoda, K. Cameron, H. Di, T. J. Clough, S. Carrick, B. Elberling, and K. Smits, "Identification of plant soil water and soil aeration corequisites: A management tool," *Soil Science Soc of Amer J*, 2024.

[8] R. S. Velazquez-Gonzalez, A. L. Garcia-Garcia, E. Ventura-Zapata, J. D. O. Barceinas-Sanchez, and J. C. Sosa-Savedra, "A review on hydroponics and the technologies associated for medium- and small-scale operations," *Agriculture*, 2022.

[9] S. Scott and C. Villouta, "Dissolved oxygen limitation and pythium root rot in strawberry nft systems: Mechanisms, research gaps, and prospects for substrate-free production," *Frontiers in Plant Science*, 2026.

[10] I. A. Lakhiar, H. Yan, T. N. Syed, C. Zhang, S. A. Shaikh, M. Rakibuzzaman, and R. B. Vistro, "Soilless agricultural systems: Opportunities, challenges, and applications for enhancing horticultural resilience to climate change and urbanization," *Horticulturae*, 2025.

[11] K. Saito and E. Goto, "Lighting design optimization in a plant factory using an optical simulation and differential evolution," *Horticulturae*, 2025.

[12] G. Barrett, P. Alexander, J. Robinson, and N. Bragg, "Achieving environmentally sustainable growing media for soilless plant cultivation systems - a review," *Scientia Horticulturae*, 2016.

[13] B. M. Eldridge, L. R. Manzoni, C. A. Graham, B. Rodgers, J. R. Farmer, and A. N. Dodd, "Getting to the roots of aeroponic indoor farming," *New Phytologist*, 2020.

[14] C. Vatistas, D. D. Avgoustaki, and T. Bartzanas, "A systematic literature review on controlled-environment agriculture: How vertical farms and greenhouses can influence the sustainability and footprint of urban microclimate with local food production," *Atmosphere*, 2022.