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Defining and averting syndemic pathways in aquaculture: a major global food sector

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Aquaculture now provides half of all aquatic protein consumed globally—with most current and future production occurring in low- and middle-income countries (LMICs). Concerns over the availability and application of effective policies to deliver safe and sustainable future supply have the potential to hamper further development of the sector. Creating healthy systems must extend beyond the simple exclusion of disease agents to tackle the host, environmental, and human drivers of poor outcomes and build new policies that incorporate these broader drivers. Syndemic theory provides a potential framework for operationalizing this One Health approach.

KEYWORDS

aquaculture, food, disease, sustainable, health

What is a syndemic?

Syndemic theory extends our interpretation of disease beyond traditional medical definitions of morbidity, co-morbidity, and multi-morbidity to include societal, economic, and environmental drivers contributing to, and exacerbating, detrimental health outcomes (Singer et al., 2017). This “biosocial” concept of disease, first applied to SAVA (substance abuse, violence, and AIDS) in individuals and groups from low-income urban environments (Singer, 1996), has subsequently been deployed where infectious and non-infectious conditions interface with prevailing political, societal, and environmental factors (Moussavi et al., 2007; Zinsstag et al., 2011; Mendenhall, 2013). Syndemic theory was re-animated by the COVID-19 pandemic, with a diverse outcome disease state associated with infection by a novel viral pathogen and the differing political, environmental, and demographic landscapes operating across susceptible human host communities (Mendenhall, 2020; Fronteira et al., 2021). Syndemic theory has important consequences for human health policy, identifying the need to move beyond biomedical intervention to simultaneously focus on tackling socio-economic disparities underlying poor health (Singer et al., 2017; Horton, 2020).

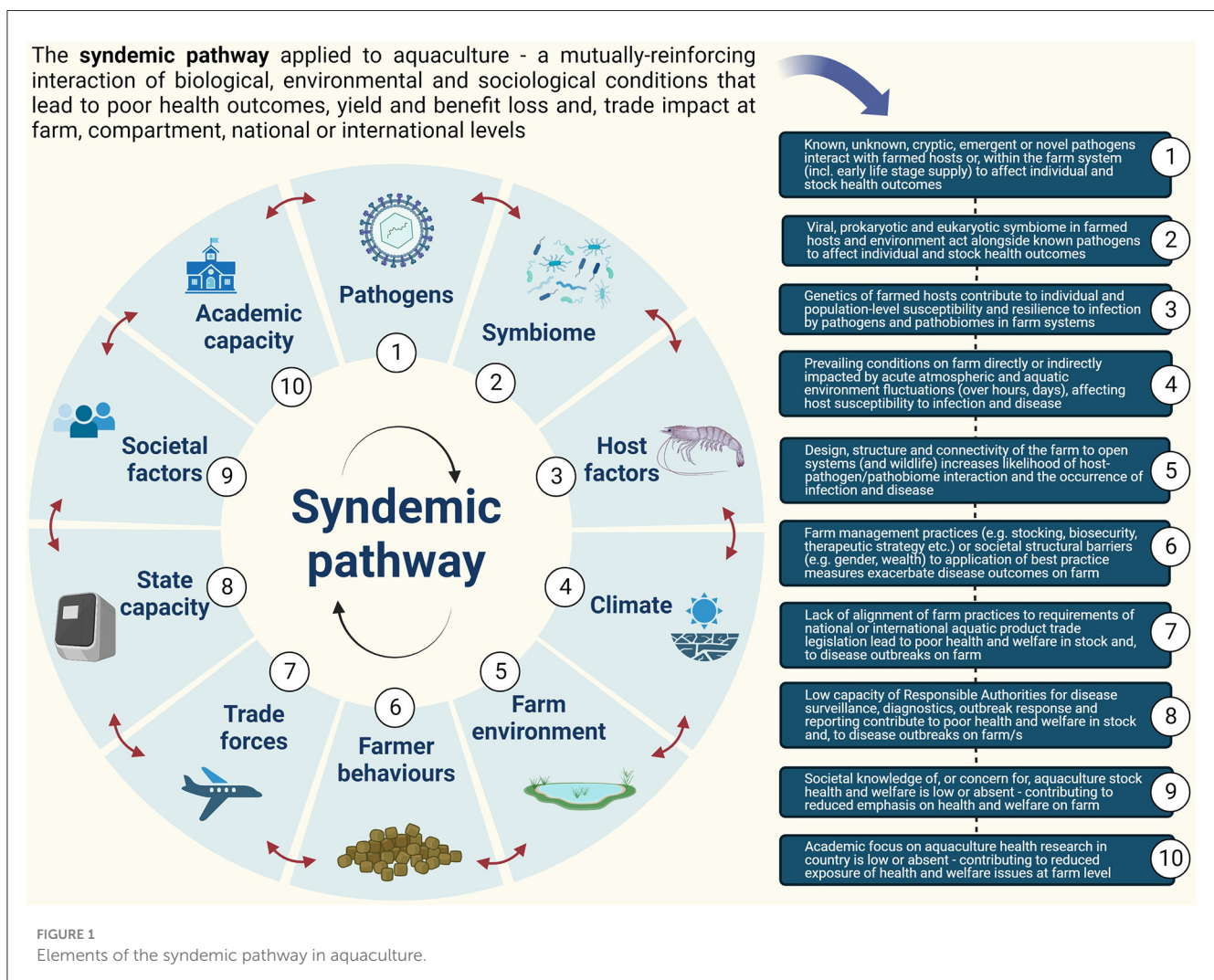
Syndemic pathways in aquaculture

In this study, we consider how syndemic theory may be applied elsewhere—specifically, to animal health outcomes within food systems. Aquaculture, one of the fastest-growing food sectors, predominates in LMICs (Stentiford and Holt, 2022). Interacting biological, environmental, social, and political factors have contributed to diseases that have seriously limited yield, benefits, profit, and food security from the sector, both in LMICs and in higher-income nations, over recent decades (Faruk et al., 2004; Solomieu et al., 2015; Abolofia et al., 2017; Tang and Bondad-Reantaso, 2019; Stentiford et al., 2020, 2022; Patil et al., 2021; Ward et al., 2021). The role of animal disease as a poverty trap for LMIC farmers, in particular, has been discussed in this context—an improved biosocial evidence basis to understand causality, to design policy, and to drive public-private investment are cornerstones of the Global Burden of Animal Diseases (GBAD) approach to reducing risk (Huntington et al., 2021; Rushton et al., 2021). The discourse on the role of disease in aquaculture has shifted focus from the presence of the pathogen (Stentiford et al., 2017) to the traditional epidemiological triad model for disease (Snieszko, 1974) revised to acknowledge that hosts and

pathogens are elements of, and not distinct from, the environment (Dohoo et al., 2009). However, now the need to extend beyond this paradigm seems critical for averting losses (Stentiford et al., 2020). Instead, we propose that a “syndemic pathway” is driving poor health outcomes in aquaculture (Figure 1), and we urge that wider-ranging factors from biological to systemic failings of the institutional environment be incorporated into national strategies aimed at underpinning sustainability in the sector.

Pathogens

Diverse pathogen taxa are implicated in aquaculture disease outbreaks, with international legislation aimed at limiting the spread and further establishment of specific (listed) diseases (i.e., transboundary diseases) via the trade in animals and products (WOAH, 2022). Single pathogens are important in syndemic pathways (Munkongwongsiri et al., 2022; Niu et al., 2022), but the need for wider consideration of the symbiome within which known pathogens exist is acknowledged (Bass et al., 2019). In aquaculture, disrupted endemic microbial consortia co-contribute to “crop production” (non-listed) diseases that are significant drivers of



farm losses (Kooloth Valappil et al., 2021; Delisle et al., 2022). Diagnostic innovations used to profile these consortia in hosts, feeds, and water are influencing better microbial management practices on the farm, which leads to improved health, welfare, and yield (Bentzon-Tilia et al., 2016; Heyse et al., 2021; Holt et al., 2021). For averting syndemic pathways in aquaculture, profiling (and managing) microbial consortia conducive to healthy outcomes is likely to be as important as doing so during outbreaks (Elements 1 and 2, Figure 1).

Hosts

Sub-optimal water quality, nutrition, and the microbial ecosystem catalyse disease outbreaks in susceptible hosts (Murray and Peeler, 2005; Bateman et al., 2020). Susceptibility is also rooted in the genetics of farmed individuals and populations at local, national, and global levels. Selective breeding (Gjedrem and Rye, 2018; Houston et al., 2020), gene editing (Gratacap et al., 2019; Potts et al., 2021), and vaccinology (Ma et al., 2019) are critical tools for promoting health (Stentiford et al., 2017, 2020)—resilient populations being those in which effective genetic management reduces disease burden, reduces susceptibility to environmental change, and maintains diversity (You and Hedgecock, 2018). Resilience extends beyond single traits (Frank-Lawale et al., 2014), but it can be situation specific. For example, genetics for environmentally controlled biosecure farming may focus on enhanced growth traits, whilst for open systems, resilience to multiple stressors, and pathogens in combination may be required (Sae-Lim et al., 2016; Houston et al., 2020). Understanding functional bases for genetic resilience in major farmed aquatic species across the range of environments in which they are cultured is a critical component for sustainability in the sector (Element 3, Figure 1).

Environment

The immediate farm environment, farm management practices, and the impact of high-level forcing factors (e.g., climate change) play key roles in aquaculture syndemic pathways (Naylor et al., 2021; Panicz et al., 2022). On farms, sub-optimal water quality causes physiological stresses that can lead to immunological damage to stock, whilst also driving pathogen virulence (Kennedy et al., 2016). Farming intensity (Oddsson, 2020), mismanagement of waste (Granada et al., 2016), and poor biosecurity (Subasinghe et al., 2019; Reverter et al., 2020; Stentiford et al., 2020, 2022) combine to create conditions conducive to disease. Vulnerability to outbreaks is further compounded by the incursion of wildlife and vegetation, surrounding land use, pollution, erosion, and the presence of disease vectors (Soto et al., 2019; Bouwmeester et al., 2021; Stentiford et al., 2022). Preventing the development of syndemic pathways in aquaculture requires minimizing the impact of these complex environmental factors on the farmed stock. Spatial planning is critical to ensuring that aquaculture develops where environmental impacts on and from aquaculture are minimal. In some cases, physical separation of the farm from

the environment or emerging precision technologies is needed to minimize environmental interactions (Føre et al., 2018) (Elements 4, 5, Figure 1).

People and society

The socio-cultural and economic context sets rules and enforcement mechanisms that shape a very specific institutional environment (Rushton and Leonard, 2009). This can create structural barriers (e.g., gender, language, knowledge, wealth, age, and access to facilities) that prevent farm operatives from obtaining adequate training and adopting practices to de-risk production. These barriers exacerbate pathogen, host, and environmental elements of the syndemic pathway—and *vice versa*, resulting in catastrophic disease losses in the sector (Kumar and Engle, 2016). Farmer behavior also directly influences the effectiveness of disease management and reporting decisions (Brugere et al., 2017; Hidano et al., 2018). The globalized nature of trade and diversity in forms of seafood consumption increase the risk of disease spread and exposure to human pathogens (Macpherson, 2005; Rodgers et al., 2011; FAO, 2012, 2020; Rinanda, 2015; Stentiford et al., 2022). National policy choices and priorities for disease surveillance, reporting, and control (including compensation for lost income), investments in animal health research, standard enforcement (notably regulation of trade), choice of farmed species, land use planning, and development (e.g., location of farms in the wider landscape), and public health policies and institutions' funding and outreach are often insufficient and disharmonized (van Herten et al., 2019; FAO, 2020). This not only has direct negative outcomes for animal and human health (Rushton et al., 2007) but also catalyses the formation of syndemic pathways that indirectly impact human prosperity (Elements 6–10, Figure 1).

Averting syndemic pathways

Whilst control of disease in aquaculture is a responsibility shared by the government and producers, the operationalization of One Health Aquaculture (Stentiford et al., 2020) can only be led by the government. By holistically conceptualizing human, environmental, and organism health, the syndemic pathway provides a framework for the government to operationalize One Health Aquaculture. Alongside national aspirations for expanded aquaculture output (Stentiford and Holt, 2022), it should catalyze the co-development of policies that extend well beyond attempts to exclude or manage the hazard (pathogen) to ones that drive investment in developing resilient hosts, protecting farms from the environment, and (particularly) exposing the core potential of humans operating within food systems to avert syndemic pathways from forming (Brugere et al., 2017).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GS: Conceptualization, Funding acquisition, Methodology, Writing—original draft, Writing—review and editing. CT: Conceptualization, Writing—original draft, Writing—review and editing. RE: Conceptualization, Writing—original draft, Writing—review and editing. TB: Conceptualization, Writing—original draft, Writing—review and editing. SM: Conceptualization, Writing—original draft, Writing—review and editing. CB: Conceptualization, Writing—original draft, Writing—review and editing. CH: Conceptualization, Writing—original draft, Writing—review and editing. EP: Conceptualization, Writing—original draft, Writing—review and editing. KC: Conceptualization, Writing—original draft, Writing—review and editing. JR: Conceptualization, Writing—original draft, Writing—review and editing. DB: Conceptualization, Funding acquisition, Methodology, Writing—original draft, Writing—review and editing.

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Conflict of interest

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