Using systems thinking and open innovation to strengthen aquaculture policy for the United Nations Sustainable Development Goals

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ABSTRACT

In a world of nine billion people and a widening income gap between the rich and poor, it is time to rethink how aquaculture can strengthen its contribution to the second UN Sustainable Development Goal (SDG) of zero hunger in our generation. The disparity in the level of sustainable aquaculture development at present, between and within countries, especially regarding human access to farmed aquatic food remains highly variable across the globe. This paper offers a fresh look at the opportunities from using systems thinking and new open innovation measuring tools to grow sustainable aquaculture. Political will in many nations is the main constraint to aquaculture in realising its potential as an: accessible source of micronutrients and nutritious protein; aid to meeting conservation goals; economic prosperity generator where benefits extend to locals and provider of indirect social benefits such as access to education and well-being, among others. Resources to enable strong partnerships

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(SDG 17) between academia, civic society, government and industry should be prioritised by governments to build a sustainable aquatic food system, accessible to all, forever.

KEYWORDS

aquaculture, food security, open innovation, sustainable development goals, systems thinking,

1 | INTRODUCTION

Sustainable aquaculture, simply described as growing aquatic organisms with human intervention, has not realised its full potential in terms of aiding progress towards the UN Sustainable Development Goals (SDG ; www.un.org/sustainabledevelopment/sustainable-development-goals/). This short position paper reflects on drivers, issues, constraints and options to build this sector in the right way by sharing different perspectives, including those from a government chief scientific adviser.

The SDGs are a collection of 17 global priorities set by the UN Development Programme in 2015, that include: end hunger, achieve food security and improve nutrition (SDG 2); ensure healthy lives and promote well-being (SDG 3); promote sustained, inclusive and sustainable economic growth (SDG 8), and; conserve and sustainably use the oceans, seas and marine resources for sustainable development (SDG 14). Herein, I argue for broader debates on how aquaculture could strengthen its contribution to meeting the SDG targets. Systems thinking and open innovation (Stead, 2018) are discussed as opportunities for improving knowledge exchange through wider engagement. In particular, applying good governance principles to involve scientists, government, industry and civic society in decision-making is highlighted in the context of strengthening evidence-led aquaculture policy (Krause & Stead, 2017; Turner *et al*., 2017).

Meeting the demand for protein, within environmental limits, is one of the biggest challenges for the global food system in the 21st century (FAO 2018). Demand for protein, in all its forms, is expected to grow significantly as an increasingly affluent global population reaches over 9 billion by 2050 (FAO, 2018). Aquaculture is one possible solution yet to realise its full potential in feeding a population of nine billion people. Its role in supplying essential proteins and micro-nutrients could be advanced through a more focussed strategy to grow the right type of aquaculture, in the most appropriate location at the best time. Natural resource management decisions, especially when aquatic space is limited, should include people and interested parties likely to be affected (Krause *et al*., 2015; Stead, 2018). Governments are sometimes less clear about the criteria for prioritising use of aquatic resources compared with its terrestrial counterpart, agriculture. This uncertainty can influence the strength of political will in supporting aquaculture sector development. If a more ambitious growth strategy for aquaculture is realised, using good governance principles (Stead, 2015; Krause and Stead, 2017), aquatic farming could influence SDG 2 of zero hunger in our generation. Herein, I argue aquaculture could support a greater proportion of the global population in access to healthy lives and better well-being (SDG 3) through improved integration in government development of food security policy. Wider consideration of benefits associated with enhancing biodiversity through aquaculture is recommended, where appropriate. Systems thinking combined with new open innovation tools is discussed as a way to help overcome constraints associated with sustainable development of aquaculture (Stead, 2018). Both are approaches that could be more widely adopted by governments and decision-makers.

2 | A BRIEF HISTORY OF AQUACULTURE

Aquatic farming of fauna and flora is centuries old, however, its modern day form is a relatively young industry that is highly regulated in developed countries (Stead, 2015; Bush *et al*., 2019). The earliest form of fin-fish aquaculture consisted of trapping wild aquatic animals in lagoons, ponds or shallow lakes, so that they would be available at all times throughout the year. This method dates back to the Neolithic age, when humans first started to act on natural resources, *c.* 6000 B.P., in Europe (European Commission, 2018). Carp, *Cyprinus carpio* L. 1758 rearing was perfected in China as early as the 2600 B.P. (Nash, 2011), although it was not until the Middle Ages that similar pond farming techniques began to develop in Europe, particularly in monasteries that needed a non-meat source of food for the many days of fasting imposed by the Christian faith. In southern Europe, fish farming in brackish water also dates back to this time, when lagoons and coastal ponds were first established to retain fish swept in by the tide, including seabass *Dicentrarchus labrax* (L. 1758) , seabreams (Sparidae) and mullets (Mugillidae; Stead, 2015). From the late. 1800s, rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) dominated European fish farming. This American species proved to be better adapted to aquaculture than its European cousin, the brown trout *Salmo trutta* L. 1758: it is hardier, grows faster and can withstand higher rearing densities. Tilapia *Oreochromis niloticus* (L. 1758) farming was first introduced to the Caribbean, Latin America and the U.S.A. in the 1940s (Nash, 2011). In the late 1960s, the advent of floating offshore cages made the farming of Atlantic salmon *Salmo salar* L. 1758 possible in Europe. The hatchery stage had been perfected years earlier and the next step was then taken of fattening young fish at sea in floating cages until they reach adulthood (Stead *et al*., 1999; Stead & Laird, 2002). European *S. salar* farming subsequently became a major aquaculture success story of the 1970s and 1980s (Stead, *et al*., 2002). Owing to its scarcity in the wild, *S. salar* had become a luxury product (Kaiser & Stead, 2002). Farms cropped up in fjords and bays in the North Sea and west of the British Isles, especially in Norway and Scotland (Nash 2011). In recent years, the Asian catfish *Pangasianodon hypophthalmus* (Sauvage 1878), commonly known as pangasius, has achieved impressive success as a commercial aquaculture species worldwide. The rate of sector growth from small family-run farms to multi-national owned production units, but continues to attract negative comments, particularly regarding effects of the sector on the environment (Kaiser & Stead, 2002). This is despite huge improvements to reducing environmental effects in recent years and clear socio-economic benefits provided to local communities (Stead, 2005; 2015; Ateweberhan *et al*., 2018).

3 | DRIVERS FOR SUSTAINABLE DEVELOPMENT OF AQUACULTURE

The concept of systems thinking is not new in aquaculture (Edwards, 1998), but some countries, Oman for example, argue that this approach and a lack of a tool for measuring aquaculture innovation efficacy, has constrained development of their national aquaculture sector (Al-Belushi, 2018). Aquaculture, if sustainably resourced and managed, can give back more to the aquatic environment than humans take. This can happen when fishery-dependent communities have an alternative or supplementary source of desired farmed finfish to wild-caught fish, thus mitigating pressure on vulnerable fish stocks (Stead, 2002; Stead, 2015; Krause & Stead, 2017; Ateweberhan *et al*., 2018). Similarly, aquatic ecosystems can benefit from an improved health status from introduction of best aquaculture management practices, such as restocking, habitat enhancement, which increase environmental quality in areas where bad practices such as over fishing and groundwater pollution from land has led to damaged ecosystems.

Traditionally, finfish production was seen by many governments as an alternative or supplementary source of protein to terrestrial animal varieties, or marine wild-capture fisheries, providing subsistence or income to fishery-dependent communities (Kaiser & Stead, 2002). This view is however changing with fin-fish aquaculture now seen as an environmentally responsible form of farming and a strategic solution to mitigating food insecurity. Island nations, the Seychelles for example (but also many countries in the Caribbean), are investing in setting-up finfish aquaculture for the first time to improve national food security resilience. In the case of the Seychelles, this is part of a national policy focussed on the blue economy where marine aquaculture has been selected for investment to underpin long-term economic prosperity and social development in the islands. In particular, concerns around depleted wild stocks have led to locals demanding action to ensure seafood supplies and job security (Philpot *et al.*, 2015), a situation that has also been repeated throughout the Caribbean and particularly in Cuba and Jamaica where farming tilapias is well established, although having declined in recent years (FAO, 2017).

Herein I address the question of how aquaculture, especially finfish, can help countries achieve progress towards the UN SDGs. The hypothesis for debate is, that sustainable aquaculture should be better integrated in wider aquatic and terrestrial food security policy, using systems thinking and open innovation approaches to achieving the UN SDG 2 of zero hunger. Advances in fundamental and applied aquaculture are central to its sustainable development and enhancement of species production worldwide. This contribution reflects on selected issues and constraints to aquaculture in realising its full potential in eradicating food insecurity and contributing to the other 16 SDGs in our lifetime.

4 | ISSUES: SYSTEMS THINKING AND OPEN INNOVATION

Aquaculture in many governments falls under ministries concerned with terrestrial food security or fisheries or the environment. The lack of visibility and complexity of the sector which cuts across different institutional portfolios, for example, trade, employment and environment means aquaculture is fragmented. Hence, aquaculture systems thinking is important for developing integrated policy which links issues at local, national, regional and international levels (Stead, 2018). Systems thinking is an approach that is based on the belief that component parts of a system will act differently when viewed in isolation from other parts of the same system. Standing in contrast to reductionist thinking, systems thinking for aquaculture sets out to view whole structures in a holistic manner (Stead, 1996). In practice, systems thinking encourages us to explore inter-relationships (context and connections), perspectives (each participant has their own unique perception of the situation) and boundaries (agreeing on scope, scale and what might constitute an improvement). Systems thinking is particularly useful in addressing complex or wicked problem situations (Kreuter *et al*. 2004) and was highlighted as a useful framework in support of developing sustainable aquaculture by Edwards (1998). Stead in 2018, recommends application of new open innovation tools (Al-Belushi *et al*., 2018) with systems thinking as a way to measure growth performance of natural resource sectors such as aquaculture to provide assurance about risk to investors and governments.

5 | CONSTRAINTS

A lack of political will is a major constraint to development of sustainable aquaculture in many countries. Part of the challenge is the availability of evidence fit for policy making that governments can use to balance decisions on generating economic prosperity when deciding on which sectors to grow whilst maintaining good environmental health of aquatic ecosystems and realising social benefits. Despite aquaculture being the fastest growing food production sector in the world, the rate of expansion varies greatly between countries with the slowest growth being observed in a number of developed countries (Stead. 2015; FAO, 2018). The negative image associated with some types of aquaculture used for food production, for example, salmon farming, can constrain governments in willingness to give their support to this sector when effective campaigns lobby against this activity. Nonetheless, advances in the biology, behaviour, husbandry and technology of cultured aquatic organisms and their application to services beyond food production, such as biodiversity enhancement is being considered more by governments under pressure to show progress towards the SDGs (Stead, 2018).

A broader look at the role of aquaculture specifically, using systems analysis for understanding different future scenarios is overdue. Prioritisation of aquaculture research areas that can be applied to support responsible aquaculture development and therefore tackle SDG 2 among the other 16 goals, needs attention so that the science required for advising food security policy, is adequately funded and is available in the future for aquaculture relevant to the local context where implementation is planned. Stead (2018) recommends governments make better use of new open innovation tools (Al-Belushi *et al*., 2018) that can measure the performance of aquaculture businesses and projects to give greater assurance about the risks involved. The lack of integration and systems thinking between different policy advisory groups in some governments is constraining the breadth of discussion required to fully understand the role aquaculture can play in helping countries meet the targets outlined in the SDGs.

An example of where systems thinking is currently lacking in helping to formulate aquaculture policy (Stead, 2018) is the limited use and uptake of integrated multi-trophic aquaculture (IMTA) models (Troell *et al*. 2009; Kleitou *et al*., 2018; Reid *et al*., 2019).

IMTA refers to studies or farms which encompass more than one species at a time from different trophic levels and habitats. A common example might include farming together finfishes, seaweed and shellfishes at the same location. Many biologists and aquaculture producers specialise in understanding or growing one particular species, with little regard for the opportunities and synergies that might arise from growing multiple organisms together. Similarly, there has been much debate in Europe about the potential for co-location of aquaculture facilities, among offshore wind-turbines (Buck *et al*., 2018), but this has often come to nothing or had limited success. The lack of systems thinking and in particular concerns about insurance, access, regulations, risk or governance issues (Christie *et al*. 2014; Krause & Stead, 2017) is constraining the positive effect aquaculture could have on people and the aquatic environment. This is why countries like Oman are embracing open innovation tools that can measure the efficacy of aquaculture companies to help develop the future size and shape of the aquaculture industry by measuring successful outcomes Many aquaculture sectors, especially fin-fish share the same aquatic environment, markets, supply chains with other food resource sectors like wild-capture fisheries. As indicated earlier, a lot of government departments responsible for aquaculture and fisheries are run in parallel. These sectors should be viewed together as part of a highly inter-connected global system and cannot be viewed in isolation. Hence, it is timely to rethink how we use systems thinking with open innovation in contemporary aquaculture policy making (Stead, 2018), where big data and digital technology can improve evidence-based decisions through improved participatory governance (Stead, 2005; Turner *el al*., 2017). The next section discusses some of the concerns underpinning negative images about aquacultures' interactions with wild fisheries and its dependence on fish for feeds (Naylor, 2009; Jennings, *et al*., 2016; Troell, *et al*., 2016) which influence governments' appetite to grow the sector.

Capture fisheries production has stabilised at *c*. 90 Mt year^{-1} over the past decade, while aquaculture production has increased from 13 Mt in 1990 to nearly 80 Mt in 2006 (FAO, 2018). This increase in aquaculture production has been achieved particularly through the culture of low-value freshwater fish in East Asia. Governments reliant on vulnerable fisheries to feed its people and provide jobs, are exploring how sustainable aquaculture can help meet the shortfall in food and income generation. While the role of aquaculture in satisfying the global demand for fish is well recognised, there are also some concerns over the potential negative consequences of aquaculture growth for marine fish stocks (Kristofersson & Anderson, 2006; Naylor *et al*., 2000; Troell *et al*., 2016; Golden *et al*., 2017). Aquaculture and other animal food production systems depend on fishmeal as food and primary source of protein, lipids, minerals and vitamins. Around 50% of global aquaculture rely on feed inputs, fish meals and oils that are essential ingredients of many feeds, but the proportion used in feeds is declining (Naylor *et al*., 2009; Jobling, 2015; Jennings *et al*., 2016). Research continues to investigate the successful substitution of fishmeal with alternative (preferably vegetable) diets in fish feeds. Success in this research field would allow aquaculture to increase its overall fish production without threatening wild fish stocks (Lazzarotto *et al*., 2018) and help counter debates on unsustainable sources of feed ingredients.

Another major limitation to progress in overcoming grand challenges in food security, continues to be unintegrated land–sea food policy (Stead *et al*., 2002; Stead, 2005; 2015). Terrestrial and aquatic food research and supply chains commonly operate in isolation of one another in many nations yet could benefit from greater sharing of knowledge exchange, particularly in deploying smart technologies to enhance sector growth. Transforming equitable access to finfish globally requires a revolution in how aquaculture is implemented (Krause *et al*., 2015). Open innovation tools (Al-Belushi *et al*., 2018) can assist different countries by demonstrating measurable benefits for governments, researchers and industry in outcomes arising from co-developed aquaculture policy for sustainable sector growth. A systems thinking approach can help target advances in aquaculture biology to build a broader sectoral policy that considers resource needs in complex multi-level governance contexts. For example, knowing what species might better withstand future climate change scenarios at different localities could be mapped against national priorities for production and considered alongside international conventions and trade opportunities. This can only be achieved through strong partnership working (SDG 17) and open innovation.

6 | OPPORTUNITIES

Global fish production reached an all-time high in 2016 of 171 Mt, of which 88% was utilised directly for human consumption. This reflected relatively stable wild-capture fisheries production, reduced wastage and continued aquaculture growth, resulting in a record-high per capita consumption of 20.3 kg (FAO, 2018). Between 1961 and 2016, the average annual increase in global food fish consumption (3.2%) outpaced population growth (1.6%) and exceeded that of meat from all terrestrial animals combined (2.8%; FAO, 2018). Never before has aquaculture attained such a high profile as part of the broader food security science policy agenda. Producing farmed aquatic organisms can reduce demand on unsustainable alternatives such as overfished populations and thereby contribute indirectly to natural resource conservation goals. Earlier development of the sector in some countries has been linked with adverse effects on the environment. In recent years, aquaculture is perceived more commonly as part of a new sustainable food production sector that offers many additional benefits to food including increased biodiversity. Aquaculture has been widely promoted as a means of lifting people out of poverty, providing a new source of income and helping to build resilience. Tanzania piloted sea cucumber (Hollothuroidea) aquaculture for the first time as a way of offering fishery-dependent communities an alternative or supplementary livelihood against the backdrop of depleted finfish stocks (Slater *et. al.*, 2013a). The main constraints to a commercial start-up for this species was a lack of reliable electricity for the hatchery, no national policy on aquaculture to direct resources for production and a lack of incentives for investment to develop this sector despite interest secured from a foreign investor. Local communities showed interest in the role aquaculture could play in enhancing depleted stocks of wild sea cucumbers and in its role in promoting conservation goals more broadly, but a lack of political will constrained progress in up-scaling sea cucumber aquaculture in Tanzania (Stead, 2015).

The potential for aquaculture as a biodiversity enhancement tool is in its infancy and the opportunity for this sector to contribute to conservation could be advanced if systems thinking was more widespread. One area of conservation action where juveniles have benefitted from completing early stages of their life cycle in cultured conditions to increase survival rates is in restocking programmes for wild-fishery management. Successful aquaculture generally relies on mirroring conditions experienced by organisms in the wild, which requires a good knowledge in the biology and behaviour of the species being grown. Nonetheless, many question the economic viability of restocking especially when hatcheries are used (Youngson, 2007). For example, in Aberdeenshire, Scotland, hatchery-reared *S. salar* parr rather than fry were recommended to be used to restock the River Don to mitigate concerns around falling catches reported over a decade by recreational anglers (Urquhart, 2012). Finfish aquaculture in this case was used as a conservation tool for rehabilitation, but there was no unequivocal evidence to show that introducing the cultured *S. salar* necessarily improved population stock levels nor that the business plan was robust. Nonetheless, knowledge from understanding the plasticity of the *S. salar* life cycle learned from aquaculture research (Stead, *et al*., 1996; 1999) was used successfully to advise fisheries managers on how best to overcome specific issues including the use of fry when restocking rivers. *Salmo salar* parr were recommended as the stage to be released into rivers to offset high mortality rates of fry that were used in earlier restocking programmes. Fry survival was observed to be lower than parr due to local competition for space and food. Understanding direct and indirect factors influencing survivability of juvenile fish in rivers is complex and requires systematic sampling to determine the cost benefits of restocking programmes (Youngson, 2007).

Some rivers have reported improved finfish population sizes using restocking programmes of hatchery-reared salmonids, especially when also tackling modifications to their habitats and water flow due to geomorphological adaptation upstream from the introduction of artificial structures. A sound business plan to evaluate cost-benefits of running a hatchery and addressing the social perceptions of introducing farmed finfish to a wild fishery are key to successful natural resource management but the detailed evidence required are frequently overlooked. Finfish aquaculture could have substantial longer-term benefits if a systems-thinking approach to aquatic conservation management, covering issues such as those reported, especially the social dimension around aquaculture as a conservation tool, was used in policy development and choice of management interventions. Local people including resource users, such as anglers, need to be engaged in natural resource user decisions from the initial planning stages if support is to be achieved.

One aspect of finfish conservation efforts that deserves more attention in an aquaculture context is the effective communication with and participation of interest groups including the recreational sector, ideally done from the agenda-setting stage. Proactive engagement is needed to establish an informed understanding of how aquaculture might affect other aquatic resource users, such as recreational anglers, commercial fishers or conservation agencies, before being introduced to collect perceived and actual concerns (Chaniotis & Stead, 2007; Little *et al*., 2018). Scholarly studies on finfish aquaculture have tended to focus on environmental and economic variables that affect the success of production, with resource users' perceptions ignored (Kaiser & Stead, 2002). The latter is important because perceptions influence attitudes that can affect human behaviour in response to natural resources management rules, such as, compliance with regulations (Peterson & Stead, 2011; Slater *et al*., 2013b; Forster *et al*., 2017; Bergseth *et al*., 2018). Aquaculture and fisheries are generally managed separately (Geffen *et. al.*, 2015) yet overlap in supply chain needs (*e.g.*, food health and safety, logistics, processing and trade, among others), thus integrating both sectors in policy would support better alignment of resource management to enable countries to improve progress towards the SDGs. Rethinking development of policy to better integrate the aquaculture and fisheries sectors is timely as governments build national and global food security resilience options to achieve SDG 2 (Jennings *et al*., 2016; Troell, 2016; Stead, 2018) and the other interlinked 16 SDGs. Future research is needed on aquaculture value chains to understand how different participants, production units, regulation, innovation and cost benefits can be better coordinated by governments to respond to regional preferences (Bush *et al*., 2019). In particular, the aquaculture sector in some northern parts of the world, such as Europe, will need to improve how open innovation is used (Stead, 2018) so that the sector can be more agile in translating its research findings into commercial reality. Urgency for this research has been highlighted by Little *et al*., (2018) who show market-based governance based on northern norms are losing leverage to southern and emerging aquaculture markets such as China.

In Europe, like many regions around the world, in contrast to Asia and China in particular, the rate of growth of the aquaculture sector has been rather modest and far from reaching the full potential it has to offer in terms of offering food and income generating opportunities. This is partly due to gaps in establishing strong partnerships (UN SDG 17) between academia, government and industry. Building strong scientific, multi and inter-disciplinary partnerships will be critical for the longer-term success in applying systems thinking and open innovation to co-creating resilient food security solutions within the aquaculture sector. Networking and establishing relationships was a key part of my work when acting as President of the European Aquaculture Society (EAS) between 2008 and 2010. EAS was established in 1975, explicitly to: (a) promote contacts between all involved or interested in marine and freshwater aquaculture; (b) to facilitate the circulation of aquaculture related information; (c) to enhance cooperation among governmental, scientific and commercial organisations and individuals on all matters dealing with aquaculture. During my tenure as an elected board member of EAS (2000–2012), I promoted interdisciplinary research as part of a systems thinking approach to developing the global aquaculture sector. This included initiatives that built partnerships with representatives from the political, economic, social, technological, legal and environmental (PESTLE) dimensions of aquaculture.

Some maritime nations, are starting to show signs of adopting a wider systems approach to aquaculture, embracing the blue growth agenda (Burgess *et al*., 2018; Eikeseta *et al.,* 2018) by considering broader socio-political, as well as ecological linkages. The PESTLE framework is being applied to prioritise activity, with the aim of achieving SDG 2 (end hunger, achieve food security) and SDG 14 (conserve and sustainable use the oceans, seas and marine resources) by identifying initiatives that can increase economic prosperity through smarter use of marine resources. Countries such as the Seychelles (and more recently Grenada) are also adopting the contested blue economy concept (Techera *et al*., 2018) and innovative financial stewardship schemes, such as the Blue Bonds to generate financial support (*c*. US $20 million from the World Bank) to improve marine food security (www.nl4worldbank.org/2018/10/31/seychelles-launched-blue-bonds-what-are-blue-bonds-faqs/). The Seychelles' government in particular has decided to focus on developing the marine aquaculture sector with a particular focus on finfish. The project will start with four species: brown-marbled grouper *Epinephelus fuscoguttatus* (Forsskål 1775), red emperor snapper *Lutjanus sebae* (Cuvier 1816), mangrove snapper *Lutjanus argentimaculatus* (Forsskål 1775) and the snub-nosed pompano *Trachinotus blochii* (Lacépède 1801). The aspiration is to reduce the country's over-reliance on wild-capture fisheries for food and income generation, as well as to supply the growing tourism industry. In the Caribbean, Grenada is one of the first countries to initiate a national masterplan for blue growth (Patil & Diez 2016). This plan identifies opportunities for blue-growth development in areas such as fisheries and aquaculture, blue biotechnology, renewable energy, research and innovation. The masterplan proposes a Blue Innovation Institute as a key component of its strategy. The institute will aim to be a centre of excellence and a think tank on blue economy, as well as seek to develop innovative blue-financing instruments such as debt-for-nature swaps, blue bonds, blue insurance and blue investment schemes (Patil & Diez, 2016). Knowledge exchange for aquaculture evidence-led policy between countries (SDG 17), such as there is between the UK and Seychelles, which share similar planning legislation, can be advanced faster using systems thinking and open innovation approaches, especially around identifying species resilient to climate change and disease. These approaches combined with state-of-the-art research in biology, social acceptability, disease risk, engineering, market governance, genetics, policy, technology, enterprise, sensors, big data and artificial intelligence, among others, will improve productivity and environmental outcomes on a global scale to support governments in meeting SDG 2 targets.

7 | CONCLUSIONS

The most important influence on realising any proposed vision of aquaculture is political will. So, what will the future of the aquaculture sector look like? Before answering this question, it is worth reflecting on how best to influence policy development such that the future size and shape of the industry can be influenced positively and be context specific. The answer is framing, framing, framing. Knowing how to frame advances in aquaculture research with local and national policy agendas to meet the big global challenges such as feeding a population of nine billion people by 2050, is important in winning political support for promoting aquaculture growth. The type (academic, government, industry and civic society) and level (local, national, regional and international) of support needed for the growth of this sector varies greatly between and within developed and developing countries (Bush *et al*., 2019). Some countries such as the UK and Canada may choose to develop new, highly efficient, high-value finfish production for niche markets whereas developing countries such as Mozambique may prefer to up-scale production of small-scale pond culture in support of domestic consumption or newer finfish species for export, e.g. cobia *Rachycentron canadum* (L. 1766). The important lesson for advancing the sector is to ensure developments are considered in a broader multi-level governance context; *i.e*., governments need to think through the intended and unintended consequences of aquaculture interventions at local, national, regional and international scales at the same time when developing policy. Doing this through a combined systems-thinking and open-innovation approach can promote transparency and trust, the fundamentals of good governance and establishment of strong partnerships (SDG 17). Thus, in answer to the hypothesis for debate, the findings herein support sustainable aquaculture should be better integrated in wider aquatic and terrestrial food security policy, using a systems-thinking and open-innovation approaches to achieving the UN SDG 2, zero hunger.

Aquaculture as the fastest growing food production sector is by far the best contemporary candidate to feed the growing global human population whilst also having huge potential to enhance aquatic biodiversity (Le Gouvello *et al*., 2017). In order to realise this vision, governments must give better consideration to the role aquaculture can play and provide adequate access to water, sufficient to sustain aquatic ecosystems. Governments should be proactive when formulating future policy with regard to employment, health, transport and water to mention a few, by giving greater consideration to co-location opportunities of aquaculture production units. Aquaculture can provide additional functions beyond food including improving water quality or as added value to aquaponics systems growing fruit and vegetables. For example, if aquaculture is introduced to an area where there is a lack of management and enforcement of water quality regulations, implementation of robust monitoring, required to meet health and safety standards before sustainable aquaculture products can be sold can mitigate pollution from land and water sources.

The protein needs predicted worldwide for projected human population growth cannot be met by terrestrial animals and fisheries alone, especially from targeted marine wild-captured fisheries. Finfish are considered by many countries as ideal candidates to provide versatile sources of protein for rural and urban communities. Jennings *et al*. (2016) have argued that aquatic food security is achieved when a food supply is sufficient, safe, sustainable, shockproof and sound: sufficient to meet needs and preferences of people; safe, to provide nutritional benefit while posing minimal health risks; sustainable, to provide food now and for future generations; shock- proof, to provide resilience to shocks in production systems and supply chains; sound, to meet legal and ethical standards for welfare of animals, people and environment.

So why has this sector not yet realised its full potential especially in addressing the SDG 2 and achieve zero hunger? Many reasons are described here but political will in support of aquaculture development is at the heart of making any future difference in real-time and in our generation. This short perspective paper highlights some common issues and constraints on future growth of the sustainable aquaculture sector to encourage a wider debate about the direction of aquaculture research. Provocative questions, such as why some finfish are viewed as aquatic chicken and other species as unhealthy food that pollute water environments, need to be debated openly and widely. If evidence-led debates around these issues are not fully addressed the contribution of aquaculture to meeting global challenges in supplying nutritious food, enhancing health and biodiversity will remain unfulfilled. Governments must integrate sustainable aquaculture developments in wider aquatic and terrestrial food security policy. This should be done using systems-thinking and open-innovation approaches to achieving SDG 2, zero hunger, and linked with progress towards the other 16 SDGs.

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