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INVITED EDITORIAL

A Fishy Story Promoting a False Dichotomy to Policy-Makers: It Is Not Freshwater vs. Marine Aquaculture

Barry Antonio Costa-Pierce[a,b], Abigail B. Bockus[c], Bela H. Buck[d,e], Sander W. K. van den Burg[f], Thierry Chopin[g,h], Joao G. Ferreira[i,j], Nils Goseberg[k,l], Kevin G. Heasman[m], Johan Johansen[n], Sandra E. Shumway[o], Neil A. Sims[p] and Albert G. J. Tacon[q]

[a]School of Marine & Environmental Programs, University of New England, Biddeford & Portland, Maine, USA; [b]Ecological Aquaculture Foundation LLC, Biddeford, Maine, USA; [c]Montana State University, Bozeman, Montana, USA; [d]Marine Aquaculture – Shelf Sea Systems Ecology – Biosciences, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany; [e]Applied Marine Biology and Aquaculture, University of Applied Sciences, Bremerhaven, Germany; [f]Wageningen Economic Research, Wageningen, The Netherlands; [g]Seaweed and Integrated Multi-Trophic Aquaculture Laboratory, University of New Brunswick, Saint John, New Brunswick, Canada; [h]Chopin Coastal Health Solutions Inc, Saint John, New Brunswick, Canada; [i]Longline Environment Ltd, London, UK; [j]Universidade Nova de Lisboa, Caparica, Portugal; [k]Division of Hydromechanics Coastal and Ocean Engineering, Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Universität Braunschweig, Braunschweig, Germany; [l]Coastal Research Center Joint Research Facility of Leibniz Universität Hannover and Technische Universität Braunschweig, Hannover, Germany; [m]Cawthron Institute, Nelson, New Zealand; [n]Biomarine Valorisation, Norwegian Institute of Bioeconomy Research, Ås, Norway; [o]Department of Marine Sciences, University of Connecticut, Groton, Connecticut, USA; [p]Ocean Era, Inc, Kailua-Kona, Hawaii, USA; [q]Aquahana LLC, Honolulu, Hawaii, USA

ABSTRACT
A recent publication by Belton et al. raises points for policy-makers and scientists to consider with respect to the future of aquaculture making recommendations on policies and investments in systems and areas of the world where aquaculture can contribute most. Belton et al. take an 'us versus them' approach separating aquaculture by economics, livelihood choices, and water salinity. They conclude "that marine finfish aquaculture in offshore environments will confront economic, biophysical, and technological limitations that hinder its growth and prevent it from contributing significantly to global food and nutrition security." They argue that land-based freshwater aquaculture is a more favorable production strategy than ocean/marine aquaculture; they disagree with government and non-governmental organizations spatial planning efforts that add new aquaculture to existing ocean uses; they advocate for open commons for wild fisheries as opposed to aquaculture; and they oppose 'open ocean' aquaculture and other types of industrial, capital-intensive, 'carnivorous' fish aquaculture. They discredit marine aquaculture rather than explain how all aquaculture sectors are significantly more efficient and sustainable for the future of food than nearly all land-based animal protein alternatives. As an interdisciplinary group of scientists who work in marine aquaculture, we disagree with both the biased analyses and the advocacy presented by Belton et al. Marine aquaculture is growing and is already making a significant contribution to economies and peoples worldwide. None of the concerns Belton et al. raise are new, but their stark statement that farming fish in the sea cannot 'nourish the world' misses the mark, and policy-makers would be wrong to follow their misinformed recommendations.

KEYWORDS
Marine and freshwater aquaculture; science; production; policy; investments

Introduction

To combat food insecurity and poverty into the 21st century, and to make progress toward the multiple impacts aquaculture can have on the Sustainable Development Goals (SDGs), we will need more healthy foods from freshwater and marine aquaculture systems, both large- and small-scale (FAO 2020). In their analysis Belton et al. (2020) neglect the significant scientific, engineering, and industry advances, across spatial scales, and in both nearshore aquaculture and aquaculture in high energy marine environments, that are not only technological but also societal. They set the salinity of water as conflict zone for future investments by governments, donors, philanthropies, and

CONTACT Barry Antonio Costa-Pierce bcostapierce@une.edu School of Marine & Environmental Programs, University of New England, Biddeford & Portland, Maine, USA.

industries, creating a false dichotomy that provides the illusion of a simplistic choice.

There are many incomplete and, from our perspective, naïve interpretations by Belton et al. (2020). We address the most important points they raise and comment on others. Most important are: (1) their misuse of information underlying the choices of systems, markets, and livelihoods by farmers at scale; (2) inaccuracies leading to their conclusion that "salmon is only available as a luxury food"; and (3) the statement that "freshwater aquaculture systems are not fundamentally resource constrained".

Others items we address are their: (1) contention that farming of 'ocean carnivores' is misguided development inherently flawed; (2) conclusion that lower trophic level mariculture has little potential for food security, and recommendation to reorder investments into small scale fisheries versus other aquatic food sector alternatives; (3) framing of the lack of compatibility between marine aquaculture and marine conservation; (4) use of the term 'offshore' while addressing many marine aquaculture issues, especially those in nearshore marine aquaculture; and (5) reviewing 'the world', then using incomplete global data to make specific local, advocacy points. Lastly, (6) the cautionary fable about a "new coalitions of actors" and "green washing" to imply some collective conspiracy is driving an increased focus on the potential for marine fish culture.

We believe that it is irresponsible for aquaculture scientists to engage in a declarative, wholesale dismissal of an entire sector that offers potential for significant reductions in overall global impacts of our food production systems (Hoegh-Guldberg et al. 2019). Belton et al. (2020) ignore the critical question that needs to be resolved: in a resource-constrained world, dominated by free markets and shaped by individual consumer choices, how do we encourage the rapid transition in animal protein sourcing away from terrestrial livestock and toward aquaculture products?

Lower trophic level marine aquaculture has great potential for food security

Bivalve molluscs such as oysters and mussels are important sources of income and employment in many communities worldwide. Figure 1 shows global aquaculture production by major species groups assembled from the latest FAO data (FAO 2021). Global mollusc aquaculture production is estimated at 17.58 million metric tonnes (MMT) in 2019, valued at over US $31.2 billion (Figure 1). Bivalve molluscs also provide key ecosystem services (Theuerkauf et al. 2021). Ferreira and Bricker (2019) estimate that bivalves remove 54% of the nutrient load from fish farming in European waters. A global expansion of species and systems for lower trophic level marine aquaculture development is occurring with the potential to make a major contribution to food security directly, and also nutritionally, due to their high concentrations of heart-healthy polyunsaturated fatty acids (PUFAs) and other essential dietary nutrients (van Ginneken et al. 2011; Grienke et al. 2014).

Filter feeding molluscs and fish species comprised over 29 MMT of total global aquaculture production in 2019 (15.78 MMT filter feeding molluscs and 13.25 MMT of freshwater filter-feeding carp species), comprising over 24% of total global aquaculture production (FAO 2021). Including the 34.73 MMT of seaweed and aquatic plant aquaculture production, total extractive aquaculture (63.76 MMT) represents 53.1%, and total fed aquaculture (56.24 MMT) represents 46.9% of the total global aquaculture production in 2019.

Belton et al. (2020) emphasize that finfish has a higher edible yield (87%) than bivalves (17%). Table 2 shows that by edible weight, marine molluscs comprise 5.5% of global farmed production of aquatic organisms. By contrast, freshwater bivalves contribute an edible weight of only 0.1% of global aquaculture. Edible yields of marine molluscs vary depending on processing which modify water contents and reduce meat weights. Cupped oysters, blue and green-lipped mussels can have edible yields of 24%, with a range from 10 to 24%. Edible yields in farmed freshwater fish are also variable; edible yields of tilapia range from 25 to 40% (FAO 1989). Economics are neglected in the assessment of the value of bivalves to farmer livelihoods. Consumers pay for the shells as well as the meat; thus, the bivalves are a high value commodity for sale and income generation in marine aquaculture.

The cultivation of marine macroalgae and aquatic plants is centered in Asia, and by weight is the second largest farmed group when considering total global aquaculture production (34.73 MMT; Figure 1). These are the largest farmed group in the world (51.3% of total production) when considering total global marine aquaculture production (Chopin and Tacon 2021).

Seaweed aquaculture is growing quickly outside of Asia: for foods, as transformers of carbon, nitrogen and phosphorus, in medicine, as well as for the ecosystem services they provide, most notably in integrated multi-trophic aquaculture (IMTA) systems in combination with fed aquaculture (Chopin 2013; Duarte et al. 2017). Farms in the USA produced an

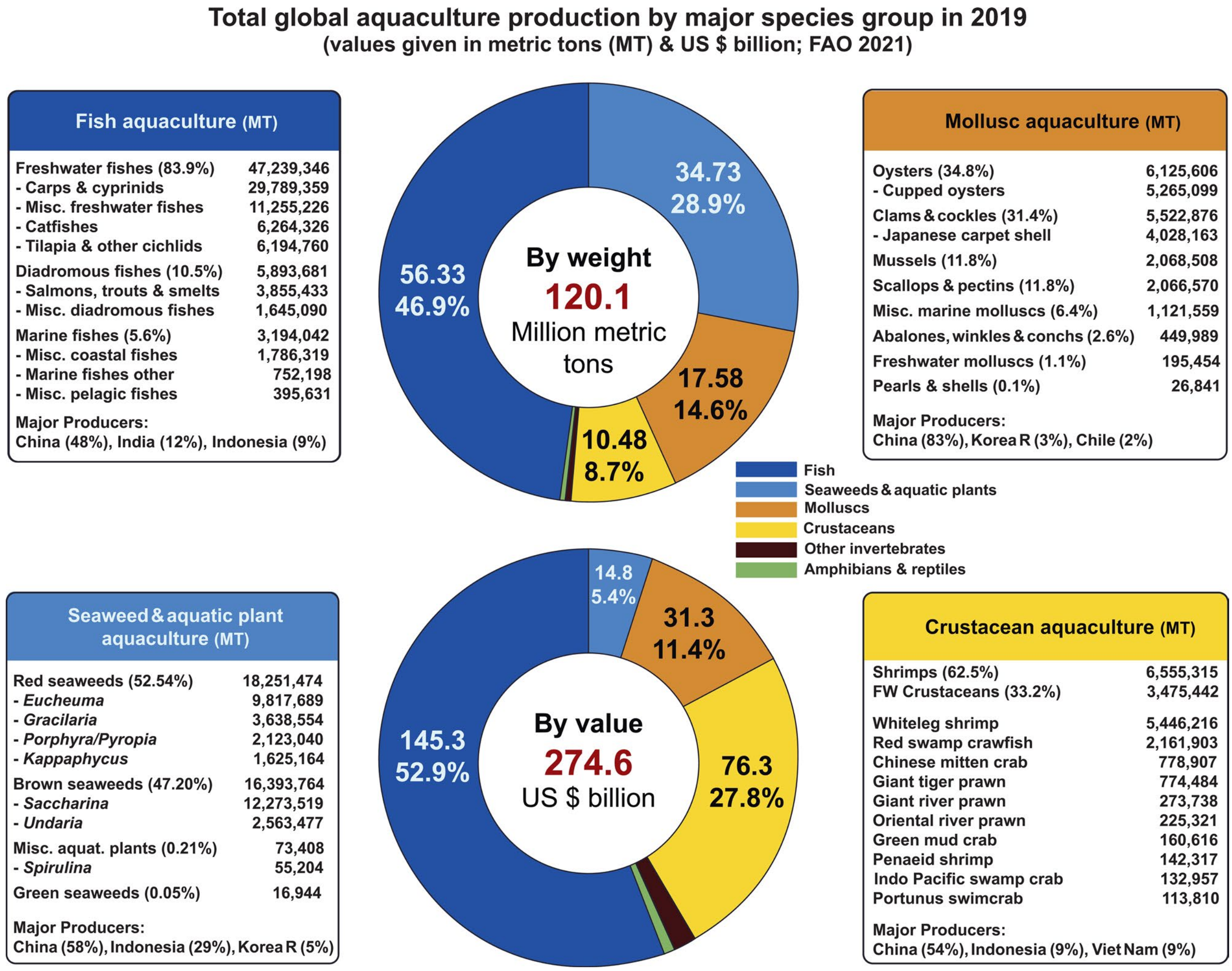

Figure 1. Global aquaculture production by major species groups in 2019. Values are in millions of metric tons and US$billion (FAO 2021).

estimated 249–272 MT in 2019 (Piconi et al. 2020). Seaweed aquaculture, on land and at sea, is progressing on both the Atlantic and Pacific coasts of Canada (Chopin 2015). In Europe, seaweeds are grown on at least 300 production units across Spain, France, The Netherlands, Denmark, Ireland, The United Kingdom, Sweden, Germany, and Norway (Camia et al. 2018; EMODnet 2021). In Norway, 163 seaweed operations produced 111 MT worth EUR 0.43 million (Blikra et al. 2020; Directorate of Fisheries 2021). Norway has allocated 834 ha to seaweed aquaculture which corresponds to a production potential of approximately 48,000 MT. Biomanufacturing opportunities are evolving rapidly to expand market opportunities for seaweeds as food supplements, animal feeds, fertilizers, packaging, and bioplastics (World Bank Group 2016; Thomas et al. 2021). Seaweed farming is also seen as a promising addition to holistic coastal protection systems for wave attenuation (Zhu et al. 2021).

Belton et al. (2020) state that a significant proportion of the seaweed production is used for unhealthy foods, which is manifestly untrue. It is incorrect to lump the alginate, agar, and carrageenan industry together with all other market options and give the image that macroalgae farming in the sea has negative impacts on the quality of food, the environment, and fisheries. Macroalgae serve as traditional foods in China, Japan, Korea, and Indonesia as well as other Asian countries and coastal communities in Europe, Canada, and the USA, and can contribute significantly to healthy diets (Delaney et al. 2016).

Farmer choices of systems and livelihoods

Belton et al. (2020) believe marine aquaculture is only accessible to large corporations. On the contrary, there are numerous examples worldwide of small to medium scale marine production where this is not the case. Table 1 points to a few noteworthy examples for their

Table 1. Some of the many examples of successful smallholder, family-owned, community-based marine aquaculture located in common property areas.

Nations	Operations	References
South Africa	Mussel farms, Saldanha Bay Aquaculture Development Area	Pritcher and Calder (1998)
Tanzania & SE Asia	Hundreds of family-based seaweed farms	Msuya and Hurtado (2017)
USA	Lobster fishing seaweed farmers, Maine	Gershenson (2020)
South Korea	IMTA fish, seaweeds and numerous invertebrates, Tsushima Strait	Hara et al. (2017)
Europe	Seaweed farming	Araújo et al. (2021)
Indonesia	Community based seaweed farming	Larson et al. (2021)
Norway	Family owned salmon farms	Edelfarm (2021), Isqueen (2021), Lovundlaks (2021), Nekton (2021), and Sulefisk (2021) Larger, family owned company for salmon R&D: GIFAS (2021)
Germany	Ocean Farm Kiel (Kieler Meeresfarm GmbH): organic certified blue mussels (*Mytilus edulis*) and sugar kelp (*Saccharina latissima*), Baltic Sea	Buer et al. (2020) and Huhnt (2019)
Germany	Sea Trout Kiel (Kieler Lachsforelle): sea trout (*Salmo trutta*), Kiel Bight	Krost and Mühl (2014)
Germany	Blue mussel (*Mytilus edulis*) on-bottom cultivation in Lower-Saxony & Schleswig Holstein	Buck et al. (2006)
Worldwide	Oyster aquaculture	Botta et al. (2020)

contrast to the opinions of Belton et al. (2020). Of particular note, not all salmon farms in Norway are large-scale, multi-national corporate entities but many are small- to medium-scale, family owned businesses. Governments have it within their power to regulate and manage marine aquaculture to restrict the size of operations, and to limit consolidation of farms into monopolistic entities.

Belton et al. (2020) ignore economies of scale, and cite cobia aquaculture as an example, stating "We believe that such a large increase in production, even if realized over a long period of time, would likely drive down cobia prices far below the current market value, undermining the economic viability of the industry and limiting its scope for expansion long before projected production volumes were reached." They fail to acknowledge that increased scales bring cost benefits due to increased efficiencies of technology; such knowledge is not limited to marine aquaculture species but also to freshwater ones (tilapia, pangasius (*Pangasianodon hypophthalmus),* etc.). Reduced prices would render farmed products more widely available. This would be beneficial to global nutrition. Furthermore, in free-market economies worldwide, increased large scale food production is driven by investment for potential future profits, which would be contingent on attractive pricing for the projected additional production. The example of cobia aquaculture is misinformed from a market perspective. There are no major commercial capture fisheries for cobia so price and volume competition is limited and market expansion can be developed solely for marine aquaculture. This is not true for freshwater tilapia which faces market competition from other 'white fish' such as cod and haddock.

Belton et al. (2020) confuse value versus production in developing their conclusion that high-value marine aquaculture species do not provide food or nutritional security. It is well known that aquaculture farmers worldwide, in all water salinities, even those farmers who are food and income insecure, have developed and trade high value species to earn income for family nutritional, educational, and other income needs. Farmers in Bangladesh developed polyculture pond systems for giant prawns (*Macrobrachium rosenbergii*) for income – not food – and also sold the larger carps in their pond systems to buy less expensive small fish for their families. Ahmed et al. (2007) stated that "although farmers produce a variety of fish, they mostly consume 70% of mola (silver carp) and 20% of carps, and none of the farmers reported to consume prawn". Costa-Pierce (1998) observed cage carp farmers in inland West Java selling – not eating – their fish and buying cheaper salted dried ocean fish from Jakarta.

The basis of sustainable livelihoods is income generation and food supply. If farmers and associated groups have access to a secure source of incomes they will, ipso facto, escape poverty. Income from high value aquaculture species helps farmers buy food and gain access to social benefits, thereby allowing farmers to withstand economic shocks and preventing families from falling into poverty. A household is food secure when it has the capacity to procure additional income as well as produce food.

Salmon – the chicken of the sea

Belton et al. (2020) assert that "salmon remains a relative luxury, inaccessible to anyone outside the global middle class". We believe that this attitude ignores the past accomplishments and future potential for further improvements in efficiencies through selective breeding, nutritional refinements and technological developments, as well as the role that pioneering salmon farming advances have made to freshwater aquaculture and that are being applied to other marine and freshwater fish worldwide (Gjedrem 2000).

Despite the active opposition to demarket farmed salmon by well-funded coalitions of anti-aquaculture non-governmental organizations (NGOs) and fishing interests (Krause 2007), farmed salmon production continues to grow with production projected to reach 4–4.5 MMT by 2030, and in value ($18 billion in 2018) (Cage et al. 2020). After review of its alignment toward sustainable development, Torrissen et al. (2011) concluded that Atlantic salmon farming can be compared to raising a marine "super chicken", elevating its production to one of the "most sustainable meat products in the world food market". The market penetration of farmed salmon has been impressive, with products available throughout the world, and being consumed not only by urban middle classes but also rural consumers throughout the Asia, Africa, Latin and South America, not only Europe and North America. The International Salmon Farmers Association (2018) estimates that it provides 17.5 billion meals/year.

It is well documented that most aquaculture jobs are not directly in production, rather in affiliated service industries (Figure 2). Aquaculture development and workforce assessments need to make sure they go beyond production planning concerns and develop comprehensive plans for localization of seed, feed, and, as much as possible, other aquaculture service industries that produce the most benefits to local economies. Investing in local institutions and employing local professionals are vitally important, especially for rural development. In Scotland, salmon aquaculture contributes to the long-term viability of many rural, coastal, and island areas, providing year-round, well-paid jobs, and supporting wider economic growth with its dispersed supply and value chains including processing, distribution, feed supplies, financial services, and exports (Weaver et al. 2020).

Freshwater aquaculture systems are fundamentally resource constrained

Expected shifts in water resource availabilities as the effects of climate change become more pronounced will inevitably limit the expansion of freshwater aquaculture. A large section of the global population is to suffer water stress by 2040. SciencesPo (2018) published an atlas of water footprint to achieve a better understanding of projected water stress in 2040 using data from the World Resources Institute. Expansion of irrigation systems in East Asia, where almost one-third of the arable land in South and East Asia is irrigated, is projected to increase more than 36% by 2050 (Bruinsma 2009). Granted, Asian societies have deep social-ecological-historical aquatic farming systems traditions that could allow for the rapid implementation, improved efficiencies, and continued sustainable intensification of freshwater aquaculture (Edwards et al. 2002). However, freshwater aquaculture in traditional pond systems can be easily compromised in a changing climate and by development. In China and India, population growth, urbanization, water shortages, pollution, and the spectacular rise of the middle classes have moved aquaculture from its traditional aquaculture geographies in rice fields and pond areas into warehouse-type buildings, recirculating aquaculture systems, and inland (Newton et al. 2021). Land scarcity due to urban expansion and accompanying price increases, together with increasing restrictions on emissions make land-based freshwater aquaculture less competitive. These are important factors to consider when making determinations of future production on land vis-a-vis marine aquaculture.

Groundwater is the primary water source for nearly half of the world's irrigated agriculture. Most of the world's major aquifers are being depleted by groundwater extraction and urbanization (Strzepek and Boehlert 2010; Jasechko and Perrone 2021; UNESCO 2021; UN-Water 2021). Land conversion of forests in Myanmar for export driven agriculture and pond aquaculture is occurring (Forest Trends 2015), just as conversion of wetland ecosystems and riparian lands in Vietnam for pangasius has occurred. With respect to both water and land use, expansion of land-based freshwater aquaculture outside of Asia to meet projected future protein demands is problematic to 2050 and beyond, especially in South Asia, Africa, and Latin/South America where the large expansion of irrigation systems is not projected (Bruinsma 2009). Freshwater aquaculture in reservoirs, notably in South America and Africa, where water levels are decreasing because of climate change, has challenges to increased agriculture and urban developments; especially if freshwater cage farms are not willing to consider reducing their fish loads as water volumes fluctuate in reservoirs (Reid et al. 2019a, 2019b).

Trophic levels and feeds

Belton et al. (2020) state that "Most marine aquaculture fish are carnivorous, especially offshore systems"

Figure 2. Salmon is job creator worldwide while occupying a fraction of ocean space in comparison to land consumption by freshwater aquaculture, and with lower carbon emissions than two of the most commonly consumed terrestrial meats. The International Salmon Farmers Association (2018) reports it produces some 17.5 billion salmon meals/year from just 0.00008% of ocean area with emissions of 2.9 kg CO_2/kg edible protein, in comparison to 5.9 kg CO_2/kg for pork, and 30.0 kg CO_2/kg for beef, creating an estimated 132,000 direct and indirect jobs [accessed 2021 Nov 04; reproduced with permission] http://www.salmonfarming.org..

and that the needs associated with marine aquaculture feeds will put more pressure on marine and terrestrial systems. This ignores the overarching imperative for expansion of all forms of aquaculture to supplant more impactful terrestrial livestock food systems (Hoegh-Guldberg et al. 2019). The term 'carnivorous' is misused. Candidates for aquaculture development are better classified as 'higher trophic level fish species' that feed higher in the aquatic food chain. The authors should be using the term 'piscivorous' in their misguided classification of species for marine aquaculture development. Salmon in the wild are not solely piscivorous, they consume aquatic invertebrates and many other foods, including fish when they have the opportunity.

There have been three stages of feed developments for aquatic species, rendering the Belton et al. (2020) argument invalid. In the first stage, technologies were developed to formulate high energy, extruded floating and sinking feeds of different sizes that meet the nutritional needs of the different life stages of farmed species. These diets were indeed formulated using marine fish meals and oils, and became very popular as aquaculture grew, especially in Asia, which became the world's largest consumers of aquaculture feeds, dominated by feeds for carps and other freshwater fish (Fry et al. 2018; Table 2). These advancements led to feed efficiency gains across aquaculture sectors resulting in efficiency metrics that equaled or significantly outperformed terrestrial livestock (World Fish Center 2011).

The second stage occurred around 2000, as development of novel sources of alternative proteins and oils and advancements in feed processing methods reduced dependence on marine fish meals and oils (Gatlin et al. 2007). Plant proteins increased in feeds by over 25% through identification and supplementation of micronutrients to ensure diets continued to meet the nutrient requirements of fish. At present, many 'carnivorous' freshwater and marine fish species can be reared successfully on diets which eliminate or significantly reduce the inclusion of animal proteins (Daniel 2018). Developments have led fed aquaculture species to become highly efficient 'ocean/aquatic omnivores' retaining their full nutritional values for human health and well-being (Statista 2010). However, these dietary shifts were accompanied by new concerns regarding environmental sustainability and fish health and welfare (Bjørgen et al. 2020; Øverland 2011).

Growing millions of tons of additional soy, wheat, pea, and other terrestrial crops needed to meet the expanding demands for pork, beef, and fish production for consumer demands, especially in Asia, has led to environmental concerns that these led to more land conversion in important Amazonian and grassland ecosystems in South America, especially for soybean agriculture (Morton et al. 2008). The driver for more soy production is the greater need for animal protein, not aquaculture per se. While salmon feeds do have a high inclusion of soya, levels are lower than pork, beef, and chicken (kg soy per kg product) (Pelletier et al. 2018). Aquaculture is the most efficient use of soybeans; if these feedstuffs were directed away from inefficient pork and beef production, a more resource efficient output of edible aquatic proteins would occur at lower environmental costs, as less freshwater would be used and lower greenhouse gas emissions would occur (World Fish Center 2011).

As a measure of their global environmental and social responsibilities, most salmon companies in Norway realized their industry's increased demands for soybeans for aquaculture feeds and ceased importing soy from Brazil (Lindahl 2014; iLaks 2019; FAIRR 2021; Saue 2021). This pro-active, science-based, industry-driven movement recognized that increased inclusion of soy protein in aquaculture feeds led to: (1) increased profitability, as soy replaced fish meal, whose prices increased and fluctuated widely; but this had the potential to shift a resource problem from the oceans onto land (Costa-Pierce 2016), (2) a decrease in the amounts of marine proteins from fish meals which moved salmon farming beyond past quandaries about 'farming up marine food webs' (Stergiou et al. 2009), and (3) salmon in aquaculture farms becoming 'aquatic omnivores'(Cottrell et al. 2021) – not carnivores as per Belton et al. (2020). Fish meals/oils are now being used in aquatic animal diets to solve issues of diet palatability and human health, and, more than ever, these feedstuffs originate from certified, sustainable fisheries or from innovative fisheries management systems planned and regulated to utilize fully and not waste bycatch resources from fisheries, as is occurring in Iceland (Government of Iceland n.d.). Some salmon aquaculture companies have also called for the use of European soy in fish feeds, which, if used by Norway, would reduce its CO_2 emissions by 41% (Byrne 2020). The most important point is to optimize the use of marine resources such as forage fish that are sustainably harvested for their value as human foods, while also optimizing the use of land-sourced feedstuffs by using them in aquaculture, rather than feeding them to cows and pigs. Soybean meal is also one of the most scaleable and least impactful protein feedstuffs for aquaculture – for both marine and freshwater species (Pelletier et al. 2018).

In stage three, rapid research and development into additional alternative ingredient sources, such as single cell proteins, insects, and algae has resulted in increasing commercial availability of these products.

Table 2. Estimated past, present, and predicted future feed use by major fed aquatic species (Tacon 2021).

Years	Trout	Salmon	Marine fish	Catfish	Tilapia	Shrimp	Chinese fed carps
2015	1,010	3,340	3,307	5,548	8,355	6,971	12,389
2019	1,222	3,731	4,293	6,677	9,900	9,020	14,389
2025	1,560	4,763	5,508	8,842	12,421	11,305	17,643
2030	1,890	5,794	6,602	11,390	14,166	13,550	20,649

Production systems are increasing in scale and prices declining as science-based feed developments accelerate, and products reach markets. Full development of these innovative alternative ingredients is a high priority for marine aquaculture scientists and industries, contributing to global priorities to develop "circular economies" to feed both marine and freshwater aquaculture species.

A review of commercial progress of these initiatives is important as Belton et al. (2020) need more information about the industry-based science advances leading to rapid commercialization as they state that "it seems probable that these products will start to substitute for fish oils as a key source of omega-3 in feeds, but the investment required means that prices are likely to remain high, limiting their use to the diets of high value species, and meaning that they are unlikely to serve as an alternative source of protein (i.e., as a fish meal replacement)."

Calysta (2020) is using Methylococcus bacteria (*Methylobacterium extorquens*), called 'FeedKind™ Protein', with a production goal of 200,000 MT/year, a significant market contribution compared to conventional fish meal factories whose annual production are approximately 500,000 MT/year. Veramaris uses the algae *Schizochytrium* to produce omega-3 fatty acids (EPA + DHA) with the algal oil having an EPA + DHA concentration exceeding 50%. Veramaris uses locally sourced sugars in its fermentation process, providing an additional benefit to terrestrial sugar beet farmers. Veramaris expects its annual production capacity will meet ~15% of the total current annual demand for EPA + DHA by the global salmon aquaculture industry (Veramaris 2018). Veramaris oils can be blended with other agricultural oils to achieve omega-3 concentrations in feed – and resulting fish – similar to those from fish oil-based diets. Algae-fed trout produced by the French supplier Truite Service are available at French retail chain Supermarche Match (White 2020). The trout were fed a commercial diet of insect proteins and an algal oil developed by Veramaris. The Norwegian salmon company Lingalaks has launched its algae oil fed salmon, and Supermarche Match reported a 12% growth in salmon sales (Undercurrent News 2019).

These biotechnological developments are positive advances for both marine and freshwater aquaculture as most aquatic feeds are consumed by freshwater fish (over 70% of estimated aquaculture feed demand in 2019 (Table 2). They will assist in decreasing the substantial amount of agricultural lands, water, and energy used in freshwater aquaculture in growing areas such as Vietnam. The 1.4 MMT of fish production in Vietnam had a "massive resource usage throughout the pangasius cradle to farm gate life cycle…estimated to be 427 million GJ exergy" (Huysveld et al. 2013). Froehlich et al. (2018) completed a comparative analysis of future feed and land use needs and found that, even if aquaculture's contribution exceeded 30% of total forage fish biomass production by 2050, more than 90% of feed crops would still be used to produce terrestrial animals, not aquatic ones. Scenarios where increased meat demands were met by both freshwater and marine aquaculture, or entirely by marine aquaculture did not change projected feed-crop requirements and total land use (Froehlich et al. 2018).

Marine aquaculture and marine conservation

Marine protected areas (MPAs) are a promising tool for increasing the sustainable yields of global fisheries (Sala et al. 2021). Areas devoted to marine aquaculture can be considered MPAs if no capture fisheries are allowed there. Belton et al. (2020) make confusing links between marine protected areas (MPAs) and marine aquaculture, stating that "marine aquaculture is incompatible with conservation objectives". The International Union for the Conservation of Nature (IUCN) has initiated an inclusive process asking, "Under what circumstances can MPAs and aquaculture come together? How could MPAs boost aquaculture growth? How could aquaculture activities provide financial support to MPAs? And how can we minimize negative interactions?" (Loffoley et al. 2019; Figure 3).

Belton et al. (2020) "interpretation" (their word, not ours) that "the push to expand marine aquaculture is part of attempts … to lay claim to and/or intensify the use of oceanic space and resources" suggests to us a fear of a coordinated conspiracy to circumvent existing ocean uses. They imply that 'offshore' aquaculture will lead to exclusion zones that restrict fishing activity. To the contrary, marine aquaculture facilities act as fish aggregating devices, which lead to improved catch rates for small-scale fisheries (the Velella-Beta and -Gamma projects in Hawaii; Haws et al. 2019; Sims and Vollbrecht 2020), or, alternatively act as refugia, protecting fish stocks. An offshore fish farm off Kailua-Kona, Hawaii has operated for over 16 years inside the Hawaiian Islands Humpback Whale National Marine Sanctuary without any negative impact on migratory humpback whales (*Megaptera novaeangliae*) (Sims 2013; BOM 2021). In the nutrient-poor waters of the Mediterranean, bass and bream farms act as attractors for wild fish, and the resulting food supply, together with the interdiction of wild capture, provide

Protected Area Category and International Name	Management Objectives
Ia – Strict Nature Reserve	Managed mainly for science
Ib – Wilderness Area	Managed mainly to protect wilderness qualities
II – National Park	Managed mainly for ecosystem protection and recreation
III – Natural Monument	Managed mainly for conservation of specific natural/cultural features
IV – Habitat/Species Management Area	Managed mainly for conservation through management intervention
V – Protected Landscape/Seascape	Managed mainly for landscape/seascape conservation & recreation
VI – Managed Resource Protected Area	Managed mainly for the sustainable use of natural ecosystem

Category	Ia	Ib	II	III	IV	V	VI
High density fish cage culture	N	N	N	N	*	*	*
High density on-land closed system fish culture	N	N	N	N	*	*	Y
Medium density on-land circulating system fish pond culture	N	N	N	N	*	Y	Y
High density shellfish culture (table, long-lines)	N	N	N	N	*	*	Y
Low density pond/lagoon fish culture	N	N	N	N	*	Y	Y
High density seaweed culture	N	N	N	N	*	*	Y
Low density shellfish culture	N	N	N	N	*	Y	Y
Medium density invertebrate (e.g. sea cucumber) culture	N	N	N	N	*	Y	Y
Integrated multi-trophic aquaculture	N	N	N	N	*	Y	Y
Restoration purpose aquaculture *	*	*	*	*	*	Y	Y

Figure 3. The International Union for the Conservation of Nature (IUCN) has developed a matrix for worldwide discussions on the fit of aquaculture systems to different MPA categories using a stop light system. IUCN correctly emphasize that this matrix requires "extensive discussion and dialogue, and…should not be taken to reflect a formal view of IUCN or its Commissions" (Loffoley et al. 2019).

habitats for dolphins, rays, and IUCN-listed species such as bluefin tuna (Callier et al. 2018). Dempster et al. (2011) found that salmon farms were not degraded marine habitats ("ecological traps") for wild fish. Rather, if salmon farms were protected from fishing – as if they were MPAs – they had potential to markedly increase wild fish populations. IMTA is compatible with MPA categories V and VI (Chopin 2018a). In Sweden, the first seaweed farm is located in its first marine national park (Chopin 2018b).

Well-planned, designed, and deployed marine aquaculture systems have been shown to improve not degrade the environment by adding essential ecosystems goods and services to aquatic ecosystems. These mirror well-planned and designed agroecosystems, and have been termed 'restoration aquaculture' (The Nature Conservancy 2021). Marine aquaculture of lower trophic level species such as bivalves, urchins, sea cucumbers, and seaweeds has the ability to improve water transparency and promote benthic restoration (e.g. of submerged aquatic vegetation), serve as buffers to coastal erosion, ameliorate nutrient pollution, provide essential habitats for other species, and transform different compounds of carbon, nitrogen, and phosphorus (Chopin et al. 2001; Beck et al. 2011; zu Ermgassen et al. 2016; Jones 2017; Alleway et al. 2019; Gentry et al. 2020; Theuerkauf et al. 2021).

Bivalves are ecosystem engineers in three ways – structural, light, and chemical (Shumway 2011; Smaal et al. 2019). Larval spillover from expanding oyster and mussel aquaculture has assisted restoration of the native green lipped mussel (*Perna canaliculus*) in New Zealand (Norrie et al. 2020) and reestablished a wild oyster fishery in Maine, USA (Delago 2021). Bivalve aquaculture expansion in these regions provided a new source of income to farmers and restored bivalve fisheries all the while meeting marine conservation initiatives in a rapidly changing climate.

Seaweeds are vital marine habitats, acting as major contributors to primary and secondary detrital food webs and oxygen production, providing ecosystem goods and services, supporting fisheries, protecting shorelines, absorbing excess nutrients, increasing water clarity, etc. (Abdullah and Fredriksen 2004; Norderhaug et al. 2005; Teagle et al. 2017; Chopin 2021). However, kelps are declining globally due to warming, water pollution, and associated food web changes (Wernberg et al. 2019; Filbee-Dexter et al. 2020). Kelp forests on Tasmania's east coast have declined by more than 95% and were listed as the first threatened marine community by the Australian government in 2012. Kelp forests need to be restored and their reestablishment through cultivation could be a way to restore their ecosystem functions. Photosynthesis takes carbon dioxide out of the water, which is the primary driver of the global climate crisis and ocean acidification. Given the global imperative for carbon drawdown, there is also the compelling possibility of carbon capture through sequestration and transformation by seaweeds, or seaweed by-products (Ortega et al. 2019; Thomas et al. 2021).

Restoration of endangered Atlantic salmon through innovation and collaboration with the salmon aquaculture industry has been led by scientists at Fundy National Park, Alma, New Brunswick, Canada using a unique rewilding strategy (Clarke et al. 2016), based upon remarkable genetic findings (Christie et al. 2016), that has returned salmon adults to their native rivers in numbers rivaling historic highs. Recovery has enhanced freshwater ecosystems impacted by reduced nutrient input caused by collapsed returns of diadromous fish. The Fundy Salmon Recovery Project is an aquaculture restoration collaboration including government, NGOs, the aquaculture industry, academia, and First Nations. Wild smolts collected from rivers are transported to the world's first Wild Salmon Marine Conservation Farm on Grand Manan Island, operated by Cooke Aquaculture Inc. with support from the Atlantic Canada Fish Farmers Association. Smolts reach sexual maturity at the salmon farm then mature adults are transported to their natal rivers and released to spawn in the wild. Since releases of marine reared Atlantic salmon began over 1000 adults have been returned to the wild to spawn. In 2021, the number of Atlantic salmon returning to the rivers of Fundy National Park has been the highest in 32 years.

Belton et al. (2020) fretting about the potential exclusion of small-scale fishers by offshore aquaculture plays on the fears of fishing communities, yet ignores the evidence that such offshore systems will occupy relatively insignificant ocean surface areas. Gentry et al. (2017) calculated that the entire volume of the current global wild fish catch could be produced from aquaculture using just 0.015% of ocean surface area, i.e. about the size of the Lake Michigan in the USA.

Misuse of the moniker of 'offshore' while addressing a diversity of marine aquaculture issues

The terms 'Open Ocean Aquaculture' or 'Open Ocean Mariculture', as well, as the term 'Offshore Aquaculture' are used inconsistently by Belton et al. (2020). For aquaculture experts and groups from marine technology, fisheries, nature conservation, as well as authorities, who act differently depending on the country, there is no standard definition. 'Offshore aquaculture' describes aquaculture installations that are subjected to strong currents, high waves, and other challenging conditions for both the species being grown, the engineering, and the people who manage them. Such conditions do not necessarily reflect the distance from the coast. To this end, International Council for the Exploration of the Sea (ICES) Working Group on Open Ocean Aquaculture scientists refer to 'exposed' aquaculture which can occur anywhere in the oceans, both near or far from shore, instead of 'offshore' aquaculture.

We disagree with Belton et al. (2020) perceptions of 'offshore' aquaculture as they mention mostly nearshore systems. We agree that capital costs increase by venturing further into the open ocean but they do not acknowledge the costs benefits of the technological advances being made such as: (1) target designed equipment for specific and larger sites and species, applicable systemically across all sites, and most certainly in less extreme sites, (2) existing 'smart operations' with sophisticated remote sensing capabilities, resulting in less ocean traffic and maintenance and greater production and harvest efficiencies (for example the autonomous boats for fish feeding and electric workboats in Tasmania and Norway), (3) methods to enhance species health resulting in less impact and greater production per unit effort, and (4) more efficient production through genetic advancement, all of which facilitate better safety and access to high energy sites and increase production that increases capital expenditures but reduces operational and management costs that increase revenues per unit efforts. Belton et al. (2020) are fixated on the status quo of offshore aquaculture technologies and do not consider the potential for improvements in operational efficiencies that result in less expensive, more widely-available products. This is akin to criticizing car phones in the 1980s as too expensive and of little benefit to broader humanity when the technology underpinning the car phone evolved over the last 3–4 decades to where most adults on Earth are connected through supercomputers in their pockets; and where cell phones are the mechanism for banking and monetary transactions that foster entrepreneurial initiatives.

Reviewing 'the world': using incomplete data to develop universal advocacy against marine aquaculture

Review papers on aquaculture which deal with 'the world' are very popular in journals today (Cottrell et al. 2019; Hoegh-Guldberg et al. 2019; Costello et al. 2020; Naylor et al. 2021); however, any analysis of the progress in marine aquaculture for its economic, biophysical, and technological merits and limitations needs to be granular to judge its contributions to incomes, food, and nutrition security. Belton et al. (2020) view the world in terms of sector growth, and use an equalizing approach in their analysis which is far too simplistic as the supply and use of aquatic foods to different regions is rife with regional social-ecological-economic diversity. Aquaculture is developing everywhere outside of Asia in its 'new geographies'. The viability of land use for aquaculture and its acceptance and cost in much of the world is very different from Asia. Few nations outside of Asia would ever consider landfilling saltmarshes to make catfish, bass, or tilapia ponds. Marine aquaculture is much more a discussion in these places (Costa-Pierce 2021).The social acceptance of occupation of space in common property resources is not comparable across geographic areas (Bush and Marschke 2014).

Setting standards to realize the greatest possible protection of 'the world' marine environment is feasible only on paper. Environmental standards differ widely. The U.S. Clean Water Act and equivalent legislation in Canada, the EU Water Framework Directive (WFD – 60/2000/EC), and Marine Strategy Framework Directive (MSFD – 56/2008/EC) place clear boundaries on what can and cannot be done with respect to aquaculture emissions. In the case of the MSFD, application of the legislation extends to the limits of national EEZs. Parameters used for assessing environmental quality are focused on ecosystem-based management, viz. the Biological Quality Elements (BQE) in the WFD such as phytoplankton abundance, biomass, and composition, or functional descriptors such as food webs, biodiversity, and eutrophication in the MSFD, and extends to xenobiotics.

Economic aspects such as markets, labor costs, and externalities are very different. Regions within Asia, Europe, and the Americas have consumers with very different preferences. Most of the farmed fish consumed in the western world is imported from Norway, or the global south. Most wild fish consumed are marine species such as cod, salmon, bass, and bream. Product presentations (filleted, whole fish, etc.) differ widely. Freshwater species such as tilapia and pangasius have found their way into the diets of Europeans and Americans where the preference is filleted or processed fish allowing these to compete on price with traditional species. In the southern European market, where consumer preferences are different, these freshwater species appear mostly in institutional contexts (canteens, retirement homes, etc.).

On the economic front, Western nations, which already import a major part of their aquatic products increasingly find imports becoming more scarce and costly as the per capita GDP of developing countries increases. Lopes et al. (2017) estimated that in less than 10 years India and China increased seafood consumption by 20 MMT, and that this is predicted to increase by an additional 14 MMT by 2025. Thus, aquaculture production in the Western World must increase significantly, and, given both the scarcity of available (and suitable) land and the preference for marine species, it is difficult to see how farming fish in the sea will not be part of the solution.

Since Belton et al. (2020) do take a global perspective, we wish to elaborate globally to illustrate how mistaken is their advocacy that marine aquaculture is not a good choice for policy-makers or investors. FAO (2020) states that approximately 96.4 MMT from fisheries and 115 MMT from aquaculture were landed in 2018 for 7.63 billion people. World population is projected to increase at about 81 million people/year to about 8.5 billion people in 2030, then to about 9.7 billion people in 2050 (United Nations 2019). Assuming the yield from fisheries and aquaculture will increase proportionally, i.e. with constant per capita consumption, at least 107 MMT from fisheries, and 128 MMT from aquaculture, would have to be provided by 2030; and 122 and 146 MMT, respectively, by 2050. Assuming that current production from fisheries can no longer be increased, a gap of 11 MMT in 2030 and 50 MMT in 2050 must be covered to meet the demand for aquatic foods. These volumes can be provided from aquaculture, if societies choose aquaculture. This additional production will require space and resources that cannot be achieved on land alone. According to the FAO, in 2018 about 87% of fish production came from freshwater and only 13% from the sea. However, if we look at the total production including crustaceans, molluscs, seaweeds, and aquatic plants, marine aquaculture exceeded freshwater production, 55% to 45%. This balance must be recognized in the FAO forecast for the years 2030 and 2050, which will result in an additional 7 MMT of marine organisms by 2030 and an additional 10 MMT by 2050. If the missing production from fisheries by 2030 and 2050 is included in the calculations, it becomes clear that global production goals cannot be achieved without the expansion of marine aquaculture. Marine aquaculture development worldwide can now be accomplished without any further pressure on invaluable fisheries. Marine aquaculture is an overall rational investment with the enormous benefit of the preservation of the world's remaining, undeveloped, and invaluable terrestrial ecosystems.

A fable about "new coalitions of actors" and "green washing"

Implications of nefarious objectives of the 'new coalition of actors' are presented by Belton et al. (2020). They portray the newly-found, broad recognition of the importance of marine aquaculture by leading environmental NGOs as treachery, rather than derived analytically to reach data-driven conclusions. They fail to recognize the progress in enhanced operating, siting, and policy measures to expand marine aquaculture sustainably that have brought together previously oppositional ocean user groups. Social constraints to accelerated production exist, but when we adhere to a social license we get a social contract (Farmery et al. 2021). Belton et al. (2020) do not provide the reciprocal analysis, i.e. will inland freshwater aquaculture feed 'the World'?

Marine fisheries and aquaculture are not mutually exclusive but can be mutually beneficial. The 'us versus them' rhetoric can be attributed to the anti-aquaculture fraternity. A new cadre of professional fishery managers are working everywhere to simultaneously preserve and recover marine capture fisheries and develop sustainable marine aquaculture in both developed and developing nations. These broadly trained professionals need our engagement, understanding, and technical support in all technical-social-ecological-economic innovations that can deliver more food to humanity than just aquaculture alone (Anderson 2002). There are emerging scientifically-based ocean food production systems that merge aquaculture and capture fisheries that have the potential to change the future of both sectors, such as capture-based aquaculture opportunities (Lovatelli and Holthus 2008).

Belton et al. (2020) feed into perceptions of marine aquaculture among some NGOs and members of the public that marine aquaculture is asking for large, new spaces for proposed developments, and that traditional uses will be overtaken (displaced, crowded, or regulated out). While aquaculture is worthy of getting more space because it can be among the world's most sustainable food-producing systems (Hilborn et al. 2018), aquaculture occupies, and plans to occupy, very small areas where its developments are the most contentious, e.g. in coastal zones and nearshore oceans. In reality, aquaculture requests for space are comparable to small, well-planned 'donut holes' in coastal oceans. For example, the total area of the very valuable salmon aquaculture is estimated at 262 km^2, or 0.00008% of the world's ocean (International Salmon Farmers Association 2018), or roughly the area of Boston, MA, a compact, medium-size city in the USA.

Marine aquaculture adds high value for a small amount of space in comparison to any other food production system. Technologies for closed or semi-closed marine fish production systems (Chu et al. 2020; Shen et al. 2021) and the recirculating aquaculture systems being constructed throughout the world largely occupy buildings akin to big box stores and service warehouses, with many being planned for abandoned infrastructure in needy rural areas suffering from job losses due to globalization and other factors.

Conclusions

Belton et al. (2020) argue that 'offshore' aquaculture is not a good idea and advocate that freshwater aquaculture and small-scale fisheries are the best investments for the future. They selectively review nearly all of marine aquaculture and depict marine aquaculture scientists and industry experts as geeks, interested in technology and ignorant of the multiplicity and complexity of issues arising regarding the environmental and social challenges faced in expanding marine aquaculture. Proponents of freshwater aquaculture and small scale fisheries are seen as progressive ecological modernists aligned against greenwashing and a corporate takeover of the oceans.

The account of Belton et al. (2020) is overly focused on the production and technical aspects of 'offshore' aquaculture but then directs policy-makers to perceived challenges and limitations of almost all of marine aquaculture. Major contributions to regional and community-based ocean foods production and the high values they obtain for farmers and communities in rural areas and for urban consumers worldwide are lost in their incomplete and biased analyses. They use outdated, reductionist, misinformed notions of the importance of value to farmers and neglect advances marine aquaculture has made to develop using best management practices, ecosystem approaches to aquaculture, circular approaches (Integrated Multitrophic Aquaculture, IMTA), spatial planning, carrying capacity, and environmental restoration to develop marine aquaculture in common property resources (Aguilar-Manjarrez et al. 2010; FAO 2010; Ferreira et al. 2013). We encourage all aquaculture scientists to let data drive their policy recommendations. Belton et al. (2020) do no reciprocal critical and comprehensive scientific examination of the challenges associated with major increases of freshwater aquaculture production on land, as we are doing to advance marine aquaculture worldwide.

Blue growth is value chains and food systems, not comparisons of freshwater versus marine aquaculture. Belton et al. (2020) misunderstand ocean farming value chains by limiting their analysis to onshore fish processing with a total lack of acknowledgement of the movement toward use of renewable energy systems in aquaculture value chains and decarbonization of global sea transport and how that will affect seafood trade (Ocean Economist 2021).

Marine aquaculture scientists and industries know well that Asian freshwater aquaculture dominates global production but disagree strongly that freshwater aquaculture worldwide should dominate global investments into the future because of food security, nutrition, and social issues. Aquaculture does have great potential in inland areas where land tenure and water rights can be secured, management, waste treatment systems are more advanced, and governance systems more straightforward than for marine aquaculture. We also see the future development of freshwater aquaculture positively due to efficiency advances and innovations coming in production science and in integrated farming practices; however, freshwater aquaculture has constraints worldwide due to the dominant use by agriculture of both water and land, by urbanization, from pollution due to nutrients and toxicants, from its own wastewater issues, and accelerated climate change.

We find it unhelpful to pit the future of aquaculture as a battle for scarce resources for aquaculture as a sector of food production versus the massive resources available for the expansion of unsustainable agriculture. Marine and freshwater communities pursuing fisheries both need high value crops for incomes to procure additional foods and commodities for both food and income security, to expand and intensify production, hire people, and send children to school, etc. The better alternative is to develop ecological aquaculture operations that create sustainable income and wealth, to integrate aquaculture into fisheries livelihoods, and to modernize fisheries, as there are far too many fishers and fishing capacity using increasingly sophisticated methodologies to catch too few fish.

We are disappointed in the adversarial nature of Belton et al. (2020). Such stances occur when interest groups do not recognize each other's interests as legitimate, and adversaries use scientific evidence selectively, contesting, and dismissing alternative views. If we follow the recommendations of Belton et al. (2020) and break into oppositional parties, there will be more fracturing of the small international aquaculture research and development community into freshwater versus marine, near- versus offshore, small-scale versus large-scale, and fed versus extractive aquaculture. We will lose our way with decision-makers, investors, communities, and consumers who are already struggling to understand aquaculture, especially in the 'new geographies for aquaculture' of the world outside of Asia.

We call for greater – not less – collaboration between freshwater and marine aquaculture in geographies new or traditional, working and learning together at all scales of production to increase food production across aquatic food systems. Land-based freshwater producers of all economic classes need more assistance to share and incorporate technological and social-ecological advancements that marine aquaculture is making, not less. There is much to share, as rich countries have regions where farmers are mired in poverty that mimics those of poor nations.

Aquaculture systems are more sustainable choices than almost all land-based terrestrial agriculture alternatives. Our world needs all of the ocean and freshwater aquatic foods it can produce sustainably to help mitigate the acceleration of the Global Climate Crisis and social changes.

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ORCID

Barry Antonio Costa-Pierce http://orcid.org/0000-0003-3059-1828

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