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David C. Little, James A. Young, Wenbo Zhang, Richard Newton,
Abdullah Al Mamun, Francis J. Murray

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SUSTAINABLE INTENSIFICATION OF AQUACULTURE VALUE CHAINS BETWEEN ASIA AND EUROPE: A FRAMEWORK FOR UNDERSTANDING IMPACTS AND CHALLENGES

David C Little[1], James A. Young[1], Wenbo Zhang[1,2] , Richard Newton[1], Abdullah Al Mamun[1,3], Francis J. Murray[1]

[1] Institute of Aquaculture, University of Stirling, Stirling, UK
[2]Key Laboratory of Freshwater Fishery Germplasm Resources, Ministry of Agriculture, Shanghai Ocean University, Shanghai, China
[3]Department of Fisheries and Marine Science, Noakhali Science and Technology University, Bangladesh

Abstract

Sustainable intensification (SI) is defined and interpreted in terms of a framework to support production of farmed aquatic animals in Asia and their trade with Europe. A novel holistic perspective to value chain analysis, informed by a range of sustainability tools, is used to explain the dynamic in the trade that is having significant impacts on livelihoods in both regions. The origins of SI in agriculture are first described and their congruence with aquaculture clarified. Asian aquaculture systems, based on their emergent properties, are then located within a SI framework considering possible boundaries (enterprise, zone or whole value chain). The implications of conventional intensification, and alternatives are explored with reference to specific examples and impacts on the local and global environment, human and aquatic animal health and welfare. The challenges to sustainability of such value chains and implications for their governance, food culture and consumer habits are considered. Local consumption of seafood in Asia is found to be a major driver of growth and alternative markets for exports regionally and in Low and Medium income countries (LMIC) are likely to impact on employment and power in the value chain between Europe and Asia. The benefits of viewing farmed seafood as part of broader food landscapes are identified in the analysis, as is a shift in the focus from volume to value in terms of goal setting. More holistic perspectives of sustainability also emerge as necessary to describe and interpret global value chains rather than limited reductionist, production- orientated views. A diversity of trends in the development of farmed seafood is identified in contrast to any simplistic move to intensification, likely informed by economic, environmental and social factors in producer and consumer countries.

Statement of relevance

Global imbalances in production and consumption of farmed seafood are stimulating trade between Asia and Europe. The dynamic of global value chains around this emergent trade and their

alignment with broader sustainability criteria, as applied to sustainable intensification of food production, are highly relevant to global food security.

Highlights

- **The concept of Sustainable Intensification is applied to the specific context of the global value chains linking production of farmed seafood in Asia and consumption in Europe**
- **Key sustainability issues are discussed that are currently not embraced by certifiers and other influential actors of farmed seafood governance**
- **Understanding demand, for the main and by-products, is critical to enhancing sustainable and more intensive aquaculture systems**

Keywords: Seafood, Asia, Europe, trade, Sustainable intensification, GVCs,

1. Introduction

Over the past decades, aquaculture in Asia has seen a rapid shift in focus from meeting local demand to it supporting global trade. Initially driven by the shrimp sector, the pattern is now repeating for lower-value white fish species such as pangasius and tilapia. The value of the overall international trade in seafood, of which the contribution of aquaculture continues to grow, now exceeds that of pork and poultry combined (Asche et al 2015). A key characteristic of this seafood trade is that there is a deficit between producer countries, that tend to be poorer, and consumer countries that are better off. The scale of this transformation has had impacts on production systems and markets in developing countries all around the world, and invites analysis of the implications for its sustainability in both producer countries and for the major destination markets. The European Union (EU) is dependent on imported seafood, with more than half its seafood consumed from imported sources (Eufuma, 2015). The EU-28 is the most valuable seafood market in the world but faced with limitations in increasing its own indigenous farmed and wild capture supplies.

With a growing demand for aquaculture to meet food and nutritional security needs in Asia itself, there is a need to explore whether farmed seafood from Asia can also continue to supply Europe's appetite. There is also a fast developing trade in seafood between Asia and other, emergent markets. For example Asia and Latin America now account for nearly half of pangasius exports from Vietnam, with China emerging as the single largest importer (Globefish, 2017). The movement of the sector towards various forms of market-based governance, such as certification and labelling schemes that promote 'sustainable' or responsible products has also emerged as an important consideration. Such measures have been criticized for increasing producers' costs and for the loss of smallholder producers from global value chains (Lee et al, 2012; Bush et al, 2013) and could encourage targeting of alternative, less discriminating emergent markets in Asia and elsewhere. Such trends coincide with a general move to more feeding of aquaculture species (Tacon and Metian, 2015) and concomitant intensification of production systems in the key Asian producer countries (Table 1). An increasing dependence on imported feedstock risks potential negative impact on the environment, both locally and globally. This, together with the market dynamics mentioned, above suggest that the resilience of the entire value chain requires assessment; limiting sustainability analysis to the farm gate ignores the importance of consumption driving production trends and the roles of the, usually more numerous, value chain actors in delivering change.

This article therefore takes a value chain approach to the concept of sustainable intensification (Cook et al, 2015), the framework that is being increasingly used in terrestrial agriculture to frame analysis and guide policy towards 'sustainable futures'. We first explain the background and major tenets of sustainable intensification and how the specific attributes of aquaculture pose particular challenges to its use before examining the major forms and alternatives to intensification of aquaculture production systems. The linkages between aquaculture and broader food landscapes are considered, as are its relationship with management of wild populations that still constitute an important part of direct human nutrition and remain important ingredients for feeds used in farming. Aquaculture is considered as part of food systems that go beyond production issues to encompass storage, distribution, trade, processing and consumption (Global Panel on Agriculture and Food Systems for Nutrition, 2016). Intrinsic to this is a need to consider the roles of aquaculture in the governance of food security i.e. the access to safe and nutritious food.

2. Sustainable intensification-origins and learning from other sectors

The concept of sustainable intensification (SI) has its roots in African smallholder agriculture (e.g. Pretty, 1997) but came to the fore with the food price hikes of 2008. Years of relative decline in interest and investment in the research and institutions supporting global food production were an undoubted stimulus but its resurgence coincided with the first World Development Report (2008) focusing on agriculture for two decades. The challenges in meeting global food security needs in the face of climate change and the rising aspirations of a growing population were acknowledged as 'The Perfect Storm' (Beddington, 2009) and the need for fresh thinking on 'food futures' recognized (e.g. The Royal Society, 2009, Garnett and Godfrey, 2012[a,b] Bostock et al., 2010). Producing more for less, whilst minimizing negative environmental impacts and optimizing societal benefit, has been a major objective of almost every development initiative in the sector in recent years. Indeed SI has since been promoted as a framework to focus on increasing yields as part of a broader approach to changes in the food system that meets the need of growing, urbanizing and globalizing markets.

The initial focus of SI on production aspects of staple crop products has since been applied to the wider food basket but also to include more holistic attributes of food systems that include demand and other societal drivers (Cook et al, 2015). There is a realization that many of the issues relating to sustainable intensification of food systems occur outside the farm boundary. Garnett et al (2013) articulate the four premises that underpin SI as (1) a need to increase production to meet greater demand for food (2) intensification to avoid further conversion of land/ water to food production thereby mitigating resultant environmental impacts 3) ensuring food security receives as much attention to increasing environmental sustainability as productivity gains and (4) SI as a goal rather than a specific *a priori* approach to achieving it. The authors also raise the need for SI to be complementary to other development goals regarding food systems and managing landscapes. These include conserving biodiversity, animal welfare, human welfare and nutrition and broader sustainable development (Figure 1).

SI has been adopted by divergent ideologies in agricultural development. It has been viewed as both a 'Trojan horse' through which small-holder agriculture will be further undermined by 'Big Ag' as well as an alternative agro-ecological or organic–led approach. Most proponents now acknowledge the importance of both ecology and technology and the necessity for rigorous testing of innovations before being widely promoted. Understanding the preconditions and motivations for intensification by producers is also essential because interest in, and adoption of, more intensive practices is not inevitable but occurs in response to a range of factors. These include opportunities for off-farm employment, availability of mechanization, irrigation, fertilizers, supply and quality requirements of commodity-markets (Boserup, 1965). The importance of governance and knowledge asymmetries has also become better understood (Pantazidou and Gaventa, 2016).

The importance of the linked issue of sustainable consumption i.e. moderating demand for high value/ impact food, especially animal source foods of which aquatic products are often key in Asia, and reducing food waste has also been identified by Garnett et al (2013) as being a key component of SI. A 'farm to fork' approach in which the value chain is central must be fundamental to SI. A combination of both life cycle assessment (LCA), assessing global impacts and understanding value chain dimensions through Global Value Chain Analysis (GVCA) present a unified approach to understanding SI in terms of the Asia-Europe trade in farmed seafood. The GVCA conceptual framework of Bolwig et al (2010) integrates environmental and poverty concerns and has been used to assess farmed seafood value chains (Figure 2). In the following sections we first consider definitions of intensity for production systems before going on to consider the other nodes in value chains. These include processing, distribution, retail, food service, consumption and post-consumption.

We first present the major drivers of the emerging trade before sketching a broad picture of Asian aquaculture as located within global food systems. The main issues for each of the four main SI premises and the interfacing policy and development goals are then addressed. We finally discuss the implications for actualizing sustainable intensification and the policy options to stimulate SI of export oriented Asian aquaculture .

3. Locating Asian aquaculture in an SI framework

Global supplies of aquatic foods continue to move towards reliance on managed stocks and away from completely open-access fisheries. Such a trend might be classed as a form of sustainable intensification along a continuum from full life cycle controlled aquaculture through culture-based fisheries, to effective common property management of wild stocks. The complexities and uncertainties of managing wild ecosystems, complex over-lapping property rights and the associated interplay of technical innovation, politics and power make SI of many fisheries an elusive long term goal. In many cases fisheries management have led to an unsustainable 'race to fish' (Hilborn et al 2003). In contrast, preconditions for private-sector aquaculture development in Asia have permitted farmer-entrepreneurs to drive rapid innovation towards improved growth and efficiency. Aquaculture has spread from a spatially and economically limited traditional form of food production to an important sector in several countries in less than two decades. This transformation – led initially by carps for domestic markets, quickly evolved to higher unit value global export commodities especially shrimp in coastal areas followed by higher volumes of lower unit-value pangasius and tilapia from inland ponds. The speed of change has been driven by increasing demand in higher-value export markets (e.g. Europe North America, and Japan) and, more recently, emergent markets. In addition, regional trade within Asia has grown considerably, as has trade between Asia and Africa (Zhang et al. 2015). In contrast to some assessments (e.g. Golden et al, 2016), most aquaculture in Asia serves domestic markets and makes significant contributions to local food security

(Belton et al, 2016). Therefore, attempts to improve the sustainability of the sector need to address domestic value chains in addition to those operating internationally.

Improving governance of food systems was identified by Garnett et al (2013) as a key need for SI. The roles and scalability of international certification in supporting the sector to intensify sustainably and enhance the environmental and social benefits of the activity have been questioned (e.g. Bush et al, 2013) but expansion of these systems continues to grow and, arguably, their influence has begun to stimulate endogenous change. Food safety concerns have been the critical driver in the emergence of domestic regulations in Asia, partly in response to bans on contaminated farmed seafood exports to developed country markets (principally the EU, the US and Japan), but increasingly as a response to the concerns of domestic middle class consumers.

The main current focus in aquaculture for environmentally-biased certification is the farm enterprise, where most direct impacts occur. This has circumvented the importance of the additive impact of geographical concentrations of production for which a zonal approach is required (Brummett, 2013; Immink and Clausen, 2017). Area-based management has been used to great effect in the UK and Norwegian salmon sectors for which such collective action has been a key part of managing sea lice problems (Berrill, 2013). Significant sector consolidation and strong regulatory capacity appear to have been key preconditions for fostering the necessary partnerships between the private-sector, government and other resource users, however. Identifying boundaries for such aquaculture zones is likely to be a major challenge, especially in contexts where management changes require collective action by large numbers of smaller, independent enterprises. Sustainable intensification of modern commercial aquaculture systems is challenged by their very openness, or porosity. Uncontrolled exposure to surrounding aquatic environments make farms, individually and collectively, both vulnerable to and a potential source of, a range of hazards. These include contaminants, excessive nutrients, exchange of pests and pathogens, genetic contamination and competition with wild species. Identifying the critical boundaries for any sustainability analysis will influence any interpretation and framing SI for aquaculture, but clearly within and near farm boundaries need consideration, as well as those delineated by value chain. Most LCAs (e.g. Pelletier et al, 2009, Newton and Little 2017) suggest that the majority of environmental impacts, probably in excess of 90%, are indirect, feed-related and thus occurring well away from the farm itself. The development of Asian aquaculture production systems is now considered together with their alignment with SI principles.

4. Pillar 1 Increased production-differentiating SI from conventional intensification

The rapid increases in both production of fish and its contribution, in both absolute and relative volumes, to total seafood consumed in Asia been achieved through both expansion in area and intensity of production over the last three decades. Aquaculture data was not even collected by the FAO until the early 1980’s and the major wave of expansion in shrimp production didn’t begin until the mid-1980s in both China and SE Asia. This has happened over different time lines in different countries in relation to a range of institutional factors; whereas farmed shrimp production exceeded wild by the late 1980’s in Thailand, it was the mid-1990s in Vietnam (Lebel et al, 2002). Moreover, whereas Thai shrimp had become uniformly intensive by 2002, in Vietnam a much wider range of production intensity continues to the present (Thanh, 2015). Conventional intensification, i.e. more product output per unit area farmed has probably accelerated in the last decade across species as hatchery and formulated feed sectors have become established. This intensification has occurred without any overt focus on achieving the key tenets of sustainable intensification (Figure 1), although these may have evolved in response to market or broader societal influences.

The key components of intensification are the maintenance of elevated stocking densities of aquatic animals through supplying nutritionally complete feeds and maintaining water quality through aeration, filtration and/or water exchange. The key sustainability issues here are common to terrestrial livestock in that they relate to the source and impacts of the feed ingredients, including water consumption, land use, and the implications of increased agricultural and fossil fuel, water and, indirectly, land derived emissions for maintaining higher productivity (Herrero et al, 2010). Traditional intensive aquaculture was highly geographically limited to contexts with suitable feeds (trash fish, abattoir waste etc.), the availability of wild juveniles of high unit value species that could be sourced from the wild (typically carnivorous species) and opportunities to exchange water through natural flow/ exchange. In contrast the availability of formulated diets and hatchery-produced seed has allowed intensive aquaculture to spread far outside its geographical origins, across a wider range of species and culture technologies. This has inevitably resulted in many trade-offs in terms of both economic and social impacts.

The key tenets to adopting an SI, as opposed to a ‘business as normal’ approach to intensification are based around regularizing and greater integration of aquaculture within food systems globally. Feed ingredients, and the diets that result, are under ever greater scrutiny regarding their ethical values and nutritional quality. Aquaculture value chains need to evolve towards meeting the nutritional and health demands of more informed, increasingly urbanised consumers that need assurance that their food has been produced in line with welfare of the key stakeholders involved, including the farmed animals themselves. The interaction between the farmed seafood sector and broader development, how it contributes to both local economies and enhancing global livelihoods through quality employment and nutrition need to become more explicit. Perceptions of aquaculture based on pioneering enterprises, often justifiably criticized for poor environmental and social outcomes, need to be re-orientated and informed by modern practice. Increasingly this will have to acknowledge the real environmental cost of producing seafood in comparison with alternatives, pushing the sector to compete with other animal source foods on every level in terms of key resource efficiencies (land, water, labor, energy). However ‘efficiency’ can be highly context specific (Garnet et al, 2015) and the emerging forms of intensification that result in greater productivity are now considered.

5. Pillar 2 Increasing productivity – emerging forms of intensification

Intensification can enhance productivity through optimizing individual health and growth, minimizing mortalities while controlling costs associated with capital investment and on-going production (Little et al. 2016, Little and Bunting, 2015). The key aspects of aquaculture intensification in Asia so far have been the use of improved nutrition through formulated diets for hatchery-produced and, increasingly, deployment of genetically improved, breeds. Such developments have resulted in rapid increases in yield compared to traditional systems.‘ Closing the yield gap’, whereby commercial yields are increased to meet that possible under more controlled conditions, has in general, lagged that achieved for arable crops and livestock. An exception is the salmonid sector and the mechanisms through which precision approaches- environmental and input control based on integrated monitoring and analysis (e.g. Foley et al, 2005; Banhazi and Black, 2009) that are increasingly applied in capital intensive food production generally can be developed and applied to aquaculture in Asia. Aquaculture species are especially susceptible to loss of performance through stress that may occur as a result of human intervention during normal husbandry activities, such as sample weighing, grading vaccination etc. Reduced and/or more targeted interventions through remote monitoring techniques has potential to significantly increase efficiency through better resource use, both through empowering better management decisions and because fish perform better when less stressed.

Most production on a global basis remains semi-intensive i.e. a significant level of nutrition is produced within the culture system. However the range in yield across semi-intensive systems is wide and there has been a rapid growth in 'fed' systems with a lower reliance on natural food production and concomitant dependence on given feed (FAO, 2016) Earthen ponds remain the dominant culture unit but within that classification there is a wide range of variation in terms of design and management for water quality and control of pests, parasites and pathogens. A comparison of farmed, exported species (Table 1) for four countries in Asia suggest great variability in terms of importance of improved strains and feeds. While improved strains are now the norm for white legged shrimp (*Penaeus vannamei*) and Nile tilapia (*Oreochromis niloticus*), in both Thailand and China, freshwater prawn (*Macrobrachium rosenbergii*) in Bangladesh and striped catfish (*Pangasiodon hypothalamus*) in Vietnam are still reliant on wild and unimproved stocks respectively. Domestication and the scientific selective breeding that becomes possible is a key component of SI.

Selective breeding to support faster growth, increased yields and improved feed efficiency and body composition traits is most advanced for salmonids where the use of molecular marker technologies to accelerate conventional selective breeding trait-improvement rates has paid dividends (Gjedrem 2012; Gjedrem *et al.* 2012).The more rapid generation times however, give tropical species, both shrimp and tilapias, a key relative advantage. Moreover, the consequences of integrated selective breeding, health management and culture system design are recognized and being implemented, increasingly within the private sector. For example, Charoen Pokphand has carried out more than 16 generations of selected breeding for growth and disease resistance for white legged shrimp in Thailand. Together with innovative pond design and management, these investments are delivering sustained and high yields despite successive and complex pathogen epidemics (Macintosh, 2016). The relatively early stage of applying science to the intensification of all these species, and therefore expected returns from future investment, can be realized when the difference in published articles between farmed salmon is compared to Pangasius when feed or nutrit* is included against these species, salmon returns more than 2000 and Pangasius less than 100 articles (Web of Science, 2016).

An emerging spectrum of intensification of culture systems suggests that differentiation between hyper-intensive systems, as defined by Welcome and Bartley (1998) as 'open' raceway and cage systems, be made with 'closed' super-intensive systems that emphasize biosecurity e.g. recirculating aquaculture systems (RAS). Closed systems potentially lead to a much lower risk of genetic contamination and pathogen–related health problems. Moreover, nutrients can be almost completely retained but these benefits come with significant energy consumption and costs. Mechanical failure and poor fail-safe, rather than disease, appear to be the main risks. The fallibility of 'completely secure' systems is however well known and impacts of highly improbable events are known to be particularly damaging (Taleb, 2008).

The degree and extent of intensification in Asia is highly variable (Table 1). Movement towards consolidation of the industry, i.e. fewer, higher yielding farms differs between countries and species. Whilst Thai shrimp and Vietnamese pangasius industries have rapidly intensified and consolidated in the last decade this has not occurred to same extent with these species elsewhere. Shrimp production in Vietnam's

Mekong Delta for example is still characterized by enormous diversity (Thanh, 2014). Culture systems range from highly extensive mixed-mangrove silviculture systems to intensive monoculture together with a variety of intermediate semi-intensive rice-shrimp systems. Here too there is a trend toward intensification, spurred by introduction of an exotic species (*P. vannamei*) more amenable to intensification than the native tiger shrimp (*P. monodon*).

A common strategy in both fresh and brackish water systems has been for farmers to reduce risk through de-intensification (reducing inputs and yields) together with diversification, usually based on polyculture within the production system (For example, see Dabaddie this issue; Belton and Little, 2011, Edwards, 2014). This has often been in response to disease losses, or risk of loss, in systems where shrimp or prawns are the primary species and intensive monocultures have been unsuccessful. Intensive cage culture in rivers of pangasius catfish and tilapia, in Vietnam and Thailand respectively, have been increasingly replaced by (lower intensity) pond production. Pond production has greater scope for control of fish health and more consistent performance is generally possible (Belton et al 2009).

6. Pillar 3 Environmental sustainability

Food production systems, both for agriculture and aquaculture (including fisheries), have been criticized for their high usage of energy and resources as well as generating wastes along their product chains (Mungkung & Gheewala 2007). Aquaculture, however, appears to have attracted a particularly high level of public scrutiny for its environmental impact (De Silva 2012; Martinez-Porchas & Martinez-Cordova 2012). The criticism attracted has led to this relatively new form of food production being labelled as a "*soft target*" compared with other sectors (New 2003) and a perception within the sector that it is developing under a burden of ethical and environmental constraints that did not restrict the formative period of agriculture (Shelton & Rothbard 2006).

Rising dependence on conventional intensification can have both local and global environmental impacts. Disposal of aquaculture waste water into 'receiving waters' can lead to the capacity of natural processes to treat such water being overloaded, with consequent impacts on both water quality and the ecosystem through exceedance of the 'carrying capacity' of the system (Ross et al, 2013). Local environments can also be impacted by escapes of farmed fish (see below). Global impacts, hitherto less studied, are receiving increasing attention and are particularly associated with feed ingredients. LCA is a powerful environmental accounting approach that assesses global environmental impacts across a range of impact categories from global warming linked to greenhouse gas emissions (GHG) to acidification and eutrophication (Huysweld et al , 2013,). Ideally, they are inclusive of the entire value chain, consider the entire life cycle of production and consumption, and identify points of disproportionate impact that need priority or remedial action. They allow impacts of different types to be considered from a balanced perspective. For example, LCA demonstrates that containerized sea freight of value added products and feed ingredients is only responsible for a minor component of the cumulative impacts of farmed seafood (Roberts et al 2015).

A key issue in interpreting LCA data is the uncertainty attached to the data used (Henriksson et al, 2014[b]), how boundaries are determined between systems and how environmental burdens are allocated. A good example of this is the problem of determining an appropriate functional unit – e.g. a kg of live fish or shrimp produced or kg of fillet after processing as the basis for the comparison of impacts. Few aquaculture LCA studies compare the edible yields of different species (e.g. Roberts et al 2015). A major area of agreement however is that aquafeeds are typically the major cause of overall impacts and that the type, source and form of feed ingredients used in aquafeeds determine their impact (Roberts et al 2015, Pelletier et al 2009, Pelletier and Tydemers 2010, Newton and Little 2017). There are major differences between and within ingredient types-fishmeal from Asia for example has much higher impacts than South American meals (Nhu et al, 2016; Henrikssson et al, 2015). Such knowledge could be used to formulate lower impact feeds both on –farm or in the factory. One key issue is the widening dichotomy between the overall performance and cost of factory produced feeds and those that can be made local to their use.

There is a considerable trade-off in the scale and location of impact as systems intensify. Extensive, non-fed systems tend to have large, shallow ponds with low yields (Table 1) resulting in large direct land use impacts but low indirect impacts elsewhere. As systems intensify, the direct impacts at the farm change and more indirect impacts occur where the feed is produced. Poor quality, farm-made feeds, with little formulation may have poorer food conversion efficiency (high FCRs), resulting in low digestibility and more waste per unit of fish produced. This in turn can lead to local eutrophication of receiving waters, depending on their size and capacity. Ingredients tend to be locally produced and minimally processed so energy inputs are low. Intensive aquaculture in many contexts is more reliant on imported ingredients (>70% in Scottish salmon feeds; Newton and Little, 2017) which are often highly processed. Global energy use is often considerably higher in intensive systems but land and water use may be lower than less intensive aquaculture overall. The cleanliness and efficiency of energy production, ingredient cultivation and processing dictates global environmental impact. However, well formulated feeds, delivered at optimum rates result in high feed efficiency with less waste. Greater feed efficiencies, in turn, lead to reduced, global and local emissions.

A historic reliance on marine ingredients in the diets used in intensive aquaculture has been a major point of criticism by environmentalists (e.g.Naylor et al, 1998). Much of this criticism was linked to poorly regulated fisheries that have resulted in over exploitation, causing damage to marine ecosystems and biodiversity (see below). Ever increasing substitution with vegetable ingredients, more for economic reasons, than environmental, has been largely welcomed. However, the increase in vegetable ingredient use has increased pressures on other sensitive ecosystems, notably from soybean production in South America (Schmidt 2010, Roberts et al 2015, Newton and Little 2017). In LCA terms, marine ingredients perform comparably or better in most impact categories, but impacts on biodiversity between different ingredients are difficult to measure in LCA. The growing proportion of marine ingredients sourced from fishery and aquaculture byproducts or waste streams theoretically reduces overall impacts but this not always acknowledged in boundary setting and allocation decisions used in some LCA (Ayer et al 2007, Pelletier and Tydemers 2007).

Super-intensification can reduce ongoing local environmental costs through (1) advanced feed formulation that improves feed efficiency and (2) better water quality management but at a cost of larger global impacts related to use of high levels of fossil fuels. Both these factors in well-designed systems will tend to reduce the amount of waste, both solid (‘sludge’) and dissolved (wastewater), and allow its concentration prior to disposal and /or reuse. Nhut (2016) has demonstrated opportunities for waste amelioration through composting and biogas production for RAS pangasius systems. RAS systems allow for efficient and complete initial sanitation of production units to remove pests and pathogens and effective control of their further entry are major control steps. Effective recycling of water to reduce the need for regular water exchange outside of the farm also reduces disease risks. Complete isolation from surrounding environments, both physically and hydrologically, is expensive. Intensive recirculating aquaculture systems (RAS), characterized by exceedingly low water replacement rates (<10% daily; Murray et al, 2014), are limited in their use for many species and contexts by high capital and operating costs, and although they limit direct interactions with the environment, tend to be energy intensive which underpin their high impacts demonstrated by LCA (d'Orbcastel et al 2009, Samuel-Fitiwi et al 2013, Badiola et al 2017). Use of renewable energy and more efficient filtration technology in such systems could greatly reduce their overall environmental impacts. In practice, approaches mirroring those developed for intensive poultry are being introduced i.e. integrating nutrition, improved system design with other measures such as selective breeding for enhanced tolerance to specific diseases. Super-intensive shrimp ponds typically take practical steps such as bird netting, water filtration and storage and recycling on farm but total exclusion is impossible. Improved sludge removal and disposal together with breeding for tolerance to specific challenges has been implemented in the Thai shrimp sector to control both the microsporidian parasite *Enterocytozoon hepatopenaei* (EHP) and toxin-related acute hepatopancreatic necrosis disease (AHPND) (McIntosh, 2016).

7. Pillar 4 Diverse and variable approaches towards sustainable intensification

The recent history of pond aquaculture development suggests that it has often occurred in areas with low agricultural opportunity. Sites that are flood prone or at risk of salinization have commonly been converted to ponds from other land use, often rice fields. There appears to be a difference between the success of incremental intensification, the gradual increases in yields and returns as inputs are stepped up, in fresh and saline water. Relatively successful in freshwater, the development of shrimp farming in saline water has been characterized by relative failure of semi-intensive systems; a common trajectory has been a move towards very intensive, more biosecure systems, or a return to extensive systems.

Shrimp farming can be a major cause of direct local eutrophication. In contrast, extensive shrimp ponds offer environmental services as nutrient sinks and can contribute to maintaining water quality. Such systems are the norm in Bangladesh and remain a sizeable part of other shrimp sectors (e.g. in Vietnam, Indonesia, the Philippines and to a lesser extent China). Rather than having 'designed isolation' from outside environments they remain intimately dependent on them with the regularity of (usually tidal) water exchange contingent on stocking levels and nutrient retention requirements. Such exchange ensures natural feed and seed enters the systems supporting polycultures and facilitates harvest often in tandem with lunar cycles. These systems are typically improved as a first step through additional stocking of hatchery juveniles. Disease remains a major cause of loss but certain management practices can improve performance (Karim at al., 2011). Assuming low land-rents / opportunity costs for alternative productive uses, even with such losses these systems can still represent low-risk options for small-holders. In contrast semi-intensive systems lack the biosecurity of more intensive systems but investment in feed, and risk of failure through disease is much higher. For shrimp, the 'squeezed middle' is an emerging phenomenon i.e. semi-intensive systems that enjoy none of the benefits of investments in biosecurity or pathogen control characteristics of intensive systems nor the low input/low risk/low output typical of extensive systems. In contrast low trophic species of finfish, which have more complex immune-systems than crustacea (Tort et al, 2003, Arala-Chaves and Sequiera 2000) may be an optimal form of sustainable intensification in many contexts.

The productivity of semi-intensive finfish culture is extremely variable; yields may increase by a factor of 5-20 (see Table 1) over background levels not receiving managed levels of fertilization. Lower yielding ponds are typically managed to limit water exchange and thus impacts of effluents on surrounding ecosystems and 'costs' (both financial and environmental) of inputs are typically low compared to systems based on formulated diets. Farmers using supplementary feeding strategies can be less concerned about the specific nutrient levels or presentation of inputs as long as a balance is maintained with natural feed generated *in situ* within the pond. This flexibility means inputs can be opportunistically and locally sourced byproducts or wastes. In this way aquaculture can be a key part of a circular economy, obviating the opportunity cost and impacts of alternative means of disposal of such wastes. The need for water quality management (aeration, pumping) based on external energy is also typically low in such systems.

A focus on the efficiency of the aquaculture system alone, therefore, rather than the broader food landscape may be misleading. Conventional intensification based on high-performance, formulated diets can lead to large improvements in food conversion efficiencies compared to lower input systems. But semi-intensive systems based on low quality feeds and fertilizers can be more efficient with respect to overall food production if water and nutrients are shared with surrounding mixed farming systems (Little and Edwards, 2012, Phong et al 2011). Reuse of aquaculture nutrients (often >40% of those in feed) in surrounding agriculture, may reduce fertilizer requirements, and hence environmental impact, of these systems; although this is often constrained by physical design and site area limitations. A greater focus on the interrelationship and interfunctionality of aquaculture with other food production and processing is urgently required, particularly with regard to nutrient and water flows where evidence suggests further gains may be had and are likely to become all the more important in future, more competitive, global value chains (Edwards 2015).

There are significant implications of these trends towards or away from intensification for the configuration of value chains. Increasingly development opportunities for semi-intensive pond aquaculture may also be constrained, with the postulated 'ladder of intensification' (Setboonsarng, 1993) for smallholders being overtaken by a rapid rise in entrepreneur-driven intensive systems. In contrast to the ladder metaphor, entrepreneurs take an elevator to a higher level of intensity that matches their investment and returns profile. This dichotomy in which diverse, relatively low input systems co-exist with intensive systems targeting commodity markets (Belton and Little, 2011; Belton et al. 2016) could be a key part of ensuring aquatic food systems are resilient in the face of climate change and other challenges. A similar case has been for supporting mixed crop-livestock systems, especially in more marginal agroecosystems (Herrero et al 2010) rather than a continued focus on conventional intensification of commodities produced in 'high potential' contexts. Promotion of smallholder, semi-intensive aquaculture as part of water and nutrient conservation in marginal agroecosystems may have more success than in high potential areas where opportunities for more attractive off farm livelihoods and alternative land uses exist. A range of interfacing issues around intensification are now considered such as land, water and nutrient sparing and implications for biodiversity.

8. Towards other policy goals

8.1 Biodiversity impacts

Growing aquaculture can impact on biodiversity both directly and indirectly. Expansion of the aquaculture sector and resulting distribution of domesticated stocks, both indigenous and non-native species, may directly impact on local fauna and flora. Indirectly, the feed demands of intensive aquaculture may affect biodiversity both through impacts of fisheries on aquatic ecosystems (Diana, 2009) and through production of terrestrial ingredients as for livestock more broadly (e.g. Stenfeld et al, 2006). The more direct effects of aquaculture on biodiversity are first considered before the concept of resource sharing and sparing are investigated.

8.1.1 Aquaculture and biodiversity: introducing new species and strains

The recent history of aquaculture compared to other forms of food production complicates any assessment of its impacts on biodiversity. Terrestrial livestock development has focused on a few mammals and birds targeted with very intense genetic selection to increase efficiency of production under farm conditions. In contrast, aquaculture's rapid ascent has been characterized by a very large number of genetically distinct but 'unimproved' species drawn from a wide range of Phyla (Diana et al. 2013). Apart from a handful of species they have yet to benefit from selective breeding or modern genetic techniques; many are still depend on wild broodstock or juveniles (Asche & Khatun 2006), the exploitation of which can have direct biodiversity impacts on the target species and by-catch. In terms of value chains this very diversity in turn supports a greater range of environmental and social impacts than more industrialized food systems. Intensification of aquaculture also has an indirect impact on biodiversity through the sourcing of feeds from both marine and terrestrial agroecosystems, although aquaculture currently only uses an estimated 4% of total world feed ingredients (Troell et al, 2014), the proportion of marine protein and PUFAs is considerably higher. Depending on the production of volatile marine ingredient supplies, aquaculture consistently utilizes over 70% and 90% of fluctuating fishmeal and fish oil supplies respectively, with 35% of fishmeal sourced from fishery and aquaculture by-products (IFFO, 2015).

The introduction of alien species for aquaculture has often been raised as a major threat to aquatic biodiversity causing declines in native species and modifying habitats and ecosystems (e.g. Herbert et al, 2016) but the selective breeding and stocking of indigenous species raised within their natural range are as, if not more, important (Bouro et al, 2016). Control of escapes from aquaculture systems has become a key part of emerging international standards. The level of escapes and type and level of interaction of farmed with wild stocks is likely to be strongly context specific however. Often these environments are already highly modified, impacted or indeed entirely man-made and the consequences of any species change may therefore have a different biological and societal value. In some cases escapes or purposeful stocking of alien species have resulted in naturalized populations that have increased the value of surrounding fisheries (Gozlan, 2008), but there have also been instances of catastrophic losses of indigenous species through predation, pathogen introduction or habitat modification. A precautionary approach has been advanced given such risks (Leprieur et al., 2009). The likelihood of more chronic impacts of an indigenous species that have been selectively improved for culture environments that, following escape, might introgress with, and affect the fitness of, wild populations remains a fertile area for debate (Lorenzen et al, 2012).

Reduction of risks through reducing or preventing stock loss from aquaculture facilities is one component of best practice. Although absolute control of escapees is problematic, intensification and investment limits such losses considerably. New tracing techniques linking escapees back to specific facilities are likely to improve best practice (Warren-Myers et al, 2015). The economic arguments i.e. that damage to the integrity of any holding system will cause comparatively higher loss in dense, high value stocks and potential sanctions from certifiers are major incentives. Industry or market led standards aiming to reduce escapes caused by equipment failure linked to poor design, fabrication or maintenance show promise, although clearly need not be the only approach to the challenge. Such standards are likely to raise entry costs and accelerate smallholders exit from the sector however. Other methods which can prevent the genetic pollution of local strains include the use of sterile stock through triploidy, although competition with native species and welfare issues may still occur.

8.1.2 Resource sharing or sparing?

In comparison with terrestrial agriculture, the potential for aquaculture to expand into new areas without major environmental impacts has been considerable. Although many have given pessimistic forecasts of further growth for inland aquaculture based on limited freshwater (e.g. Sorgeloos, 2012) and heralded the open sea as the likely new frontier, growth of aquaculture in freshwater ponds continues to outpace all other environments (Edwards, 2015). Aquaculture can be a secondary and non-consumptive user of freshwater water stored primarily for other purposes and, depending on system design and intensity of production, can be a balanced part of aquatic ecosystems. Ponds may act as sinks to retain nutrients for reuse in surrounding food systems reducing the overall demand for fertilizers and the burden of their environmental impacts. Expansion of aquaculture into cleared or highly modified natural habitats can directly impact on biodiversity however. Degradation of both freshwater and coastal ecosystems has been historically linked to aquaculture although the extent compared to other factors has been long debated (Naylor et al, 1998, Beveridge et al 1997). The indirect impacts on biodiversity of both terrestrial and marine ecosystems through the sourcing of feed ingredients have had increased attention in recent decades. The efficiency and morality of catching fish for fishmeal in the aquaculture industry has been particularly under scrutiny (Naylor et al 2009; Alder et al., 2008), but the effects of deforestation on biodiversity for soybean and palm oil plantations have also received attention. It is estimated that around a third of agricultural land is dedicated to the production of animal feeds (Robinson et al 2013).

Biodiversity can be enhanced through either land sharing or land-sparing (Garnett et al, 2013). For aquatic systems such thinking can usefully be extended to other key resources-especially water and nutrients. There are examples of both in Asian aquatic farming systems; low input shrimp and prawn culture variously integrated with combinations of whitefish, rice and dyke cash-crops, or mangroves exploited for timber and other products are examples of land, and broader resource, sharing; these have been characterized by Bush et al (2010) as ‘landscape’ systems, in contrast to ‘closed systems’ in their assessment of resilient shrimp production. In contrast, intensification of production on smaller areas has ‘spared’ land and water at a local level. In Thailand for example intensification has led to farm area, no longer being used for production, being reconfigured for water and sludge storage. Such sludge ponds over time often develop high utility as wildlife refuges on-farm. Intensification has also led to some ponds being abandoned or converted to other uses (orchard, palm production (Banchun, 2012) with higher environmental functions.

A general shift of shrimp production from tidal mangrove areas to more elevated lands better suited to more bio-secure closed/ production has occurred particularly in countries such as China and Thailand. The same concept has been modelled by Bunting et al (2015) for reconfigured upland mixed cropping systems in which rice production was intensified, supported by on-farm irrigation storage also used for fish culture. The integration of fish into such a system boosted profits by over 70% compared to only 9% with intensified rice alone over the baseline. Rates of return to capital and payback periods were also improved. In a similar bio-economic modelling of Indonesian landscape shrimp production systems, Bunting et al (2013) found that low input systems in which stocked shrimp and fish together with naturally recruited species gave significantly better returns than traditional un-stocked systems, and had much lower risk compared to conventional semi-intensive systems or those based on integration with mangroves. Although prospective returns of integrated mangrove shrimp were relatively high, costs and management complexity were high and there were great uncertainties associated with risks. In Vietnam current management of rights in mangrove-shrimp systems appears to be undermining farmers from optimizing incomes and conserving forest resources (Ha et al, 2012), a problem exacerbated by a poor understanding of how their sustainable integration can be optimized for economic and environmental outcomes (Baumgartner et al, 2016).

Understanding the value and impacts of landscape systems is challenging. The issue of using exotic or indigenous species in what are, or quickly become, polycultures has been discussed above but in reality a reliance on both stocked and naturally recruited juveniles in extant mangrove areas is a key factor in their overall value and resilience in Bangladesh (Mamun, 2016) and the Philippines (Dabaddie et al , this volume). A core attribute of these systems is the co-production of species within ponds (polyculture) and the linkages between ponds and surrounding agriculture (Integrated agriculture aquaculture, IAA). Both are rational approaches to reducing risk and enhancing productivity and have implications for maintaining or enhancing biodiversity. Combinations of high and low value species may contribute to both local and global food security whilst stabilizing returns and reducing risk through diversification of production and market options. Polycultures may also reduce environmental impacts by reducing quantities and/or quality of required feeds. Whereas shrimp in intensive monoculture require complete formulated diets, no-feed or low feed strategies are often employed when stocked at lower densities in polyculture. The variety of species that have different spatial and feeding niches mean that overall ecological efficiency can be higher than monoculture (Milstein, 1992) The financial and nutritional returns of such polycultures and their implications for both local food security and value in export markets are discussed later.

A further key strand in sustainable intensification of terrestrial livestock has been the issue of maintaining welfare outcomes for the animals themselves and people dependent on them which is now considered for aquatic animals.

8.2 Welfare

The welfare issues around fisheries, and more recently aquaculture, have been cast in a broader ethical framework that includes wellbeing, autonomy and justice applied to different interest groups (aquatic animals , humans and the environment; Pitcher and Lam, 2012, 2015) and most recently in terms of the sustainability of the natural resource base (Lam,2016).

8.2.1 Animal welfare:

There has been relatively little attention to the welfare of farmed fish and other aquatic animals in developing countries, where ensuring the welfare of people has taken understandable precedence. Changes in the design and management of animal husbandry systems towards intensification can potentially have consequences for direct welfare outcomes (Dawkins, 2011, Fraser, 2006). Whereas smaller operations might benefit from greater traditional husbandry skills, larger and better capitalized operations should have greater capacity to invest in new technology. The development of animal welfare standards may therefore indirectly impact on the scale and ownership of aquaculture production and processing enterprises and determine the nature and value of markets targeted. Ensuring the 'five freedoms' are met (i.e. freedom from thirst, hunger and malnutrition; discomfort; pain, injury and disease, to express normal behavior and from fear and distress) is likely as challenging under extensive as intensive conditions for terrestrial (Villalba and Manteca, 2016) and aquatic animals.

There are a number of welfare issues facing farmed fish that differentiate them from husbandry and slaughter of long domesticated terrestrial livestock (Branson and Southgate, 2008). Finfish, as vertebrates, are now considered sentient, i.e. capable of feeling pain, and are increasingly subject to welfare standards as applied to conventional livestock. In contrast a large range of farmed aquatic animals are invertebrates for which there few regulations (Horvath et al. 2013) but for which there is clear evidence for their capacity to suffer. A comparative indifference to the welfare of aquatic animals may also stem from customary practices in harvesting wild stocks. Commercial fishing has typically offered little incentive to reduce stress during and after harvest, provided the eating quality or appearance of the product is unaffected. A focus on preventing death by asphyxiation for both wild and farmed stocks and use of some form of stunning prior to slaughter are generally recommended. Efforts to maintain value of both farmed and wild fish post-harvest through keeping them alive until slaughter prior to processing or retail can further exacerbate the challenge of maintaining high welfare.

Welfare issues regarding terrestrial livestock are increasingly related to the negative impacts of selective breeding toward high productivity. Such concerns have been less relevant to aquatic animals although domestication and strain improvement are now beginning to have impacts on the productivity of major farmed aquatic species. The recent movement of the Scottish salmon industry towards higher welfare production has indicated how higher welfare and better returns can be mutually compatible. An export orientation may accelerate such change when there is little domestic interest; the improved slaughter processes being initiated in Vietnam for pangasius destined for EU markets is an example of this. It is less easy to predict if such welfare initiatives will transfer to production intended for the domestic, or export to other Asian markets. However, it is worth noting that International retail multiples establishing themselves in Asian markets will remain exposed to reputational risks associated with their Western consumer-base.

The use of some types of polycultures to improve system productivity may raise issues of welfare where competition for feeding and overlapping spatial niches occur (e.g. Rahman and Verdegem, 2010) but in general high performance polycultures result from compatible and complementary use of space and food. The use of cleaner fish in salmonid production has raised issues of how their welfare can be enhanced (Treasurer, 2012) that has led to the development of specific management and diets for the cleaner fish (Lerclerq et al, 2015). Polyculture, where one species is used as the food source of another raises a particular welfare issue, raising the issue of the equivalence of welfare standards for intensive versus more extensive and natural culture systems (Villalba and Manteca, 2016).

The practice of eyestalk ablation, the industry norm for controlling shrimp maturation and post larvae production, is also coming under increasing scrutiny. Some European retailers have indicated their intention to exclude all ablation-derived stocks from their sourcing in order to improve welfare credentials and avoid media criticism. Any welfare-led changes in value-chains that require additional investment may further disadvantage small-scale actors, be they producers or traders of live juveniles or marketable fish.

8.2.2 Human welfare and nutrition

Public health issues

Both occupational and consumption related risks have been linked to the aquaculture sector. Few studies have been published on the occupational risks associated with farming and processing seafood but they are likely to be largely on par with terrestrial food products and less extreme than the fishing industry (Watterson et al.2012). Particular risks are raised through close involvement with water, particularly if electrical appliances are used; electrocution and drowning are hazardous to untrained employees and poorly managed facilities. Many risks are likely to be system specific - such as the manual removal of pond sludge by divers in deep (4-6m) pangasius ponds. In common with other forms of livestock production systems, a variety of chemical products are routinely used in aquaculture to control pathogens and optimize production and welfare of the stock (Rico et al. 2013; Ali et al,2016). The principles of SI suggest that any chemicals should be minimally toxic to both their users and non-targeted life forms, thus having minimal environmental impacts and no significant impacts on occupational and human health. Any review of the chain of custody of a farmed product shows that producers themselves may have only partial oversight of the issue for various reasons. Reliance on off-farm feeds or chemicals makes producers vulnerable. Such dependence on the practices of those manufacturing and marketing inputs gave rise to the sector-wide export ban on Bangladesh shrimp and prawn products linked to the use antibiotic contaminated ingredients for prawn-feed formulation. Both feed ingredients and formulated diets are sensitive to both purposeful adulteration or accidental contamination through often lengthy and poorly governed supply chains. Recent evidence however suggests that there has been rapid change in use of chemicals in Asian aquaculture, particularly a move away from antibiotic use, and that the main environmental risks are minor to modest, and usually below comparable aquaculture elsewhere or terrestrial livestock (Rico et al, 2013). Improving capacity to support aquatic health management at the local level, especially among knowledge-deprived smallholder farmers, has been advocated as critical for improving safe and effective use of medicines. The rise in antimicrobial resistance as a public health threat, in addition to antimicrobial residues, has given significant impetus for improved surveillance and control methods (Tuševljak et al 2013).

The use of more extensive, integrated systems also presents a different set of challenges in that contamination of supply chains may be unrelated to management of the aquatic animals themselves but rather an outcome of shared water or other resource use. For example rice-fish culture, where both are produced in the same system at the same time, and for which chemical control of rice pests is required is a good example of this. An important issue ignored by many media polemics is the assessment of comparative risk (Murk et al., 2016). Many studies have indicated that the relative risk from infectious agents, or chemical contamination is many times higher in wild unmanaged stocks than farmed seafood in Asia and this is borne out through the regular monitoring (RASFF) by the EU on imported seafood (Little et al. 2012).

Human Nutrition-Sustainable Consumption

The globalisation of farmed seafood chains raises several issues relating to their role in food security, both local to production and in distant markets. These include the impacts of intensification on product nutritional quality and, if an export orientation, impacts on access to quality food locally. Golden et al (2016) raised the issue that poor management of wild stocks and export-orientated aquaculture threatened food security in fish dependent LDCs. Their analysis failed to recognize the domestic orientation of most aquaculture among the top-ranking producer LDCs (Belton et al, 2017). A concern regarding sustainable intensification is that food produced in industrialized systems has poorer nutritional profiles. In particular it has been claimed (Bogard et al, 2017) that micronutrient profile is being sacrificed for higher yields, i.e. that more is being simply equated with 'better'. These concerns echo perceptions about modern food generally despite improvements in access to more diversified diets, of which food products derived from animals make up an increasing share (Speedy, 2003).

Access to seafood, however, remains uneven in both poorer and richer countries. A major challenge to medium income countries is addressing the widening gaps between rich and poor (Iguacel et al, 2016). The role of seafood needs consideration in the modern era when malnutrition is as likely to result in obesity as stunting and starvation. This is particularly important given the continued failure to recognize the importance of seafood in human diets (Bene et al, 2015) , as recently reflected in a lack of specific nutrition orientated indicators in the sustainable development goal related to managing aquatic resources (Sustainable Development Knowledge Platform, 2016). A recent high profile report on human nutrition failed to make any link between aquatic food and improving human nutritional outcomes because of this lack of interdisciplinarity (IFPRI, 2016)

Seafood consumption in Europe is highly variable in term of both quantity and diversity consumed between, and even within, countries (Eufuma, 2015) whilst in Asian LDCs with significant levels of farmed seafood exports, variation can also be extreme (Needham and Funge-Smith, 2014).This study also suggested that both urbanization and the rising importance of aquaculture compared to wild capture fisheries generally leads to a reduction in dietary diversity. Some research points to the substitution of a diet rich in diverse, often small, indigenous fish species by a more limited range of cultured fish could have poorer nutritional outcomes (Roos et al 2005, Bogard et al 2015). The promotion of polycultures in aquaculture systems as a mechanism to maintain or enhance both bio- and dietary diversity may therefore have implications above its importance to economic or environmental sustainability discussed above. Moreover such polycultures extend well beyond the pond boundary, with reuse of aquaculture effluents in surrounding agriculture becoming a component of more joined-up local foodscapes. This approach appears to match with a need to ensuring that production approaches address the overall dietary needs of local communities (Garnett et al., 2013). Knowledge and understanding of the mechanisms through which aquaculture, especially that with a commercial export focus, supports the food security of non-producers is limited. For example finfish and other aquatic co-products harvested from 'shrimp' ponds in Bangladesh are an important, often dominant, proportion by volume. Little research exists regarding their fate and nutritional impacts (Mamun, 2016). Moreover as traditional diets and the food marketing systems influencing their availability themselves are in flux, understanding the contributions that aquatic animals currently and potentially make becomes ever more complex.

Reviewing strategies for sustainable intensification needs a better understanding of demand-especially those aspects driving change in aquaculture value chains (Tilman et al, 2011; Davis et al., 2016).The likely impacts of political consumerism (e.g. levels of choice versus need) and sustainable consumption also deserve consideration, albeit with a realistic perspective as to what one, comparatively small sector may achieve within the wider food marketing environment. Sustainable intensification of the farming enterprise considered in isolation of the sustainability of the value chain is neither feasible nor worthwhile. Just as improving the sourcing and use of key inputs-water, labour, energy, nutrients and seed is critical, so is the marketing of products and byproducts. In North America where over consumption compared to nutritional needs is common, eating smaller portions of fish would deliver sustainability benefits (Tlusty et al, 2011) as would choosing products that are inherently low trophic species rather than high level carnivores (Oita et al, 2016). Such behaviour may actually conflict with commercial incentives and may not necessarily be front of mind in most fish consumers' purchase decisions but could be supported by better consumer information. We now consider aspects of intensified aquaculture that add value to the sector and society more broadly through reducing waste streams and supporting sustainable development.

8.3 Reducing waste

A key component of sustainable intensification is increasing output yield, and its aggregate value, for a given level of inputs. Improving the efficiency of post-harvest processing operations and the profitability of principal products and related by-products can be an important contribution especially when the limited proportion of 'prime' product is considered. The production of fish fillet or shrimp tail results in by-products-i.e. heads, frames, skins, shells etc that can be a significant part of the harvested yield and, potentially, of overall value (Newton et al 2014). The value of products from various processing stages is dynamic, their relative values may change and so the harvested yield of the traditional main product may even become secondary to the value of a current by-product. So, for example, fish gelatins, collagen, leather, various peptides, shrimp chitosan and glucosamine may have much greater unit value than the main product after further processing (Newton et al 2014). However encouraging reuse of agricultural and fishery by-products has become a contentious issue for several reasons. Many certification schemes support the use of fisheries by-products as marine ingredients in aquafeeds (GAA,2010, ASC, Global GAP, 2011) and EU legislation has recently allowed the use of mono-gastric animal by-products in aquaculture (European Commission, 2013), but the LCA community remains divided on best approaches to accounting for such reuse and to where the impacts should be attributed. While some practitioners treat by-products as a waste, that should be utilized, using economic reasoning (Papatryphon et a, 2004; Guinee et al, 2004), others attach high environmental burdens to their usage using more biological based reasoning (Pelletier et al 2007, Pelletier et al, 2011). However, the latter often does not take into account the subsequent impacts of waste disposal if the by-product is not utilized and is in conflict with certification efforts. Other regulatory and commercial barriers exist to high value utilization efforts such as for human health supplements (Raghavan and Kristinsson, 2009; Thorkelsson and Kristinsson, 2009). Implications for the trade in products and by-products between nodes of production and consumption, and their impacts on broader development, are now considered.

8.4. Rural Economy

8.4.1 Impacts on employment through growth in farmed seafood value chains

Sustainable intensification implies the strengthening of rural economies- and avoiding negative environmental as well as social consequences. Aquaculture has been subject to criticism on both counts but has been responsible for transformational as well as more incremental change in poorer parts of Asia.

Many of these changes have occurred through the poor being crucial, though often less visible, members of value chains rather than producers *per se* (Little et al, 2012). The impacts of intensification of aquaculture on people, both directly and indirectly are diverse and context dependent. Some studies have suggested (e.g. Toufique and Belton, 2014) that movement away from open access exploitation of aquatic resources to more intensified management can lead to erosion of rights and benefits to poorer groups and that consolidated intensive aquaculture in turn often results in a further narrowing of benefits (Armitage and Marschke, 2010). Such analyses rarely consider a full value chain approach which tend to indicate growth in employment elsewhere in the value chain. Faruque (2007) found that erstwhile fishers improved their social mobility through leasing and management of prawn culture ponds in Bangladesh and that manual agricultural wages increased with the boom in pangasius farming in the same country. There has been a steep rise in rural employment related to growth in the processing sector that is often a multiplier of gains compared to fish culture (Ibid). The development of wholesale auction markets close to production clusters in Bangladesh has been an important component in supporting farming and has led to significant employment generation as well as improving returns for producers (Pijl, 2014) .

Poorer migrants have often been drawn to work in the aquaculture sector, a phenomenon that has led to the associated benefits and problems having far flung impacts. Inequalities in labor conditions in the sector have been heavily criticized particularly when extreme forms of abusive practice, child and bonded labor have come to light (Amaravathi et al, 2016). In common with the garment trade and others, there is clearly an urgent need for an overhaul of governance structures and ensuring adherence to international norms; these might also be reinforced by the leverage of international trade, including responsible sourcing programmes and third-party certification systems, incorporating effective traceability systems. Pockets of bad and often illegal practice, however, should be considered in context and pragmatically. Aquaculture can support the livelihoods, directly and indirectly, of large numbers of very poor people with few other alternatives. Employment opportunities and diets in shrimp producing communities in Bangladesh had changed over time (Steinburg, 2012), but these also reflected household responses to broader development changes which are highly location specific (Dasgupta et al (2014). Remittances from legal migrant workers in Thailand's shrimp industry contribute to households throughout poorer parts of SE Asia. Aquaculture as a positive employment choice for migrants in terms of quality of life outcomes that often exceed international standards is reflected in recent studies of Thai shrimp farming (Sataporntvanit-Nietes et al 2014).

In terms of employment in general, a global assessment (Hishamunda et al, 2017) has found that aquaculture tended to both improve socio-economic conditions and increased employment, particularly non-seasonal jobs. This had a positive outcome of allowing young people to remain in rural areas, supporting their economic viability. Moreover total benefits tended to exceed those in alternative sectors. A focus on employment in the farming sector alone greatly underestimates benefits. Alexander et al (2014) reported employment in processing within the Scottish salmon sector to exceed that on farms by a factor of 4 although this work is generally unskilled and poorly paid (Hishamunda et al 2014) . In areas of high unemployment a dualistic labor market is common, characterized by high paid professionals and low paid workers. The implications for sustainable intensification on employment benefits will be highly context specific but on principle concomitant improvements in peoples' overall welfare should not be traded off against other productivity gains. Higher labour efficiencies in technologically advanced sectors such as Norwegian salmon can result in growth in quality jobs however.

Both the nature and location of processing of farmed seafood has profound implications for sustainable intensification and continuance of trade. The marketing of only value-added products to distant export markets such as the EU can enhance both sustainable production and consumption. Local processing ensures retention of 'byproducts where either they have more value as direct food- (e.g. swim bladders and fish heads) or can be most cost effectively further processed to more valuable products (e.g. leather, fishmeal, chitosan, collagen) (Newton et al 2014). Moving only the 'finished' 'fillet' or 'tail' reduces both transportation costs and any costs associated with disposal of low value waste, but if the unit value of associated byproducts alters, such tenets are unlikely to hold sway. Poorer producer countries often have better developed markets for by-products, perhaps because they are more widely accepted as direct food. GVCA suggests that a high proportion of end market value often results from further reprocessing of exported raw material within Europe and other developed country markets (Kelling, 2013). The linkages between consumption trends in export markets for Asian farmed seafood and implications for broader sustainable development are now considered.

8.5 Broader sustainable development

The challenge of feeding nutritious diets to a growing global population within planetary boundaries is a key objective of sustainable intensification of food systems in general (Foley et al, 2005; Roos et al 2017). This challenge also forces the issue of two opposing views: 'not enough food' and 'too much greed' (Garnett, 2015). The first focuses on production efficiency gains to address environmental impacts whereas the latter proposes that dietary change is required, particularly curbing the consumption of animal source food. A third narrative around food and its place in sustainable development is that of inequality rather than either production or consumption. The imbalances in supply and demand, production and consumption reflect broader distributional challenges, some of which have been considered above. Balanced nutritious diets for Western Europe in which farmed seafood is an intrinsic component are possible within a scenario of reducing greenhouse gasses to sustainable levels (Roos et al, 2016). Other research suggests that the footprint of imported seafood farmed in Asia can be significantly lower, even allowing for higher transportation related impacts than locally produced food (Roberts et al, 2016). The implications for the rapidly growing production and trade in farmed seafood on the broader food system is now discussed given the opportunities for sustainable intensification described above.

8.5.1 Value Chains-consumption drivers for SI farmed seafood

The competitive advantage of farmed Asian products compared to locally-produced, cultured and wild stocks, in both Europe and North America has been driven by cost and consistency of quality and supply. The importance of cost compared to other values, i.e. credence qualities, is subject to speculation. The latter could feasibly drive sustainable intensification practices in Asia if better understood by consumers and critically, seafood buyers and marketers. In recent history farmed seafood has found keen markets among consumers and become established, often initially through promotion in food service. This sector is, in the main, particularly cost-orientated and competitive in terms of offering new products and presentation. Novel species and related products first experienced away from home have led to regular home consumption. These trends have developed in parallel with a growth in interest for 'local' products in the same markets, undoubtedly spurred by a growing mistrust of industrial food production driven by widespread media attention on illegal practices (e.g. Gale et al, 2016). A continued rise in the importance of credence qualities of seafood is likely and products conforming to such values can be expected to gain value, possibly at the expense of food produced through conventional intensification.

Confusion among consumers regarding seafood attributes remains common however. Consumers still perceive wild seafood as available and natural (FAO, 2016), and, given the choice, prefer it to farmed. However, aquaculture has advantages that it can be delivered fresher, direct from slaughter with good welfare standards, whereas wild product may take several days to reach market after capture with no welfare standards in place. There is some evidence that consumers prefer fish farmed more 'naturally' and are willing to pay for it (FAO, 2016). However, research elsewhere, (Chambers et al 2008) suggests that as long as food is safe, in most cases price is the key driver and attribute uppermost in most fish consumers' purchase decisions. Other qualities such as convenience and perceived quality however appear to drive demand for the increasingly popular ready to eat seafood. Asian farmed seafood that can claim values that meet standards (Organic, Fairtrade etc), that are in line with credence qualities are likely to meet receptive markets and be able to more effectively differentiate from mass market products. However the extent of any price differential that can be consistently commandeered remains uncertain; for example such premium markets can be rapidly saturated by over-supply. .

Communicating broader, complex sustainability values to consumers is a major challenge and arguably one best achieved through trusted brands (Kim, 2012; Lassoued and Hobbs, 2015). Increasingly brands employ their own supply-chain assurance methods and/or demand third-party certification for their products. Such choice editors, as commercial entities, however will inevitably seek to compromise or trade –off some values over others, particularly in competitive environments. A key challenge to drive sustainable intensification by Asian producers is the development of brands based on reliable, traceable supply chains. Communicating the value and diversity of sustainable farmed seafood, whether best practice intensive systems or well managed landscape systems is a major challenge.

8.5.2. Barriers to international trade

The EU seafood supply deficit is reflected in very low tariff barriers for unprocessed seafood, a fact that might be expected to support sustainable trade into the future. Such open markets provide opportunities for EU-based value chain actors to benefit but may constrain Asian actors to upgrade (Ponte et al, 2014). Trade of seafood farmed in Asia, especially for shrimp and pangasius has developed over a relatively short time period and has been fortuitous in being able to fill a gap in supplies emergent from a number of traditional sources, not least EU capture supplies. However the growth of imports has also met with some resistance from other capture and fish farming sectors. In the US catfish farmers and producers fearing adverse impacts on their own markets (Schubert, 2012) lobbied for imposition of non–tariff barriers and capture whitefish interests attempted the same in Europe (Little et al, 2012). The significant price differentials between imported and locally produced seafood has exacerbated such trade conflicts and, on occasions, encouraged malpractice. Kulawik et al (2016) noted the variable quality of both imported pangasius and tilapia into various European markets and the common practice of fraudulent substitution for higher value species; in one study 20% of fish labelled as European plaice were in fact pangasius (Pappalardo and Ferrito, 2015).

The seafood business appears to be particularly sensitive to disruption through non-tariff behavior compared to other traded commodities. International trade in many consumer goods and services, including many food products, are long standing and accepted (e.g. bananas, coffee) but farmed seafood remains the subject of consumer confusion, exacerbated by media suspicion and entrenched interests for some categories of seafood (Little et al.2012). Whilst some part of consumers' confusion may be explained by lack of familiarity with these relatively recent and novel farmed seafood products, it still does not entirely explain market reactions. Critically, aspects of conventional production intensification have been used to undermine the perceptions of the intrinsic qualities of seafood farmed in Asia among European consumers. Such qualities include claims of contaminants in food and, abuses to local environments and people. In an era of 'food scandals', commercial interests have sought to protect their core brand values by reducing risk in their supply chains and ensuring standards and full traceability and regulators have funded research into assessing seafood specific risks (e.g. Marques et al, 2017).

The challenge to communicate comprehensive sustainability and ethical values for products sourced from extended and complex international value chains can be daunting, but arguably it is a key step towards more sustainable consumption. This will undoubtedly lead to different messaging strategies and compromises. The use of a high welfare standard for farmed salmon in the UK, for example, has been used by one supermarket to communicate overall sustainability and trust to their customers. Another illustration of this need for compromise on detail was the recent withdrawal of carbon emission levels on product packaging by another large UK retailer (Quin, 2012).

Potentially these investments towards more sustainable consumption in Europe will have positive impacts elsewhere, including Asian producer countries, as trade interconnectedness grows. Farmed Atlantic salmon exports to Asia from Europe have surged in recent years as the taste for exotic, and increasingly affordable, seafood has developed among a rapidly growing middleclass. This trend may have been fueled by fears among informed Asian consumers of weaker governance of local farmed seafood entering domestic markets (e.g. Zhou et al, 2014) and greater trust in imported products produced to international standards. Growing sales of farmed salmon in Asia and reprocessing of seafood in Asia for local and European markets has increased the linkages between suppliers and markets. Increasing levels of cross investment are likely as lead companies from the North buy into the growth potential of Asian markets and Asian actors invest in downstream businesses in Europe.

Finally, given that growth in both populations and consumer purchasing power in Asia is likely to outpace that in the EU and cultural value of seafood is greater, it is expected that a rise in local demand generally will place pressure on price. China, already a net seafood importer, exerts major influence on shrimp price and availability at certain times of year and there is a possibility that EU buyers will find low priced Asian seafood increasingly difficult to source. Enhancing productivity sustainably could ensure positive interdependence. The medium term trend suggests co-investment and a shared vision of sustainable intensification between the EU and Asia has mutual benefit.

9. Policy options for stimulating SI of export orientated aquaculture

The policy implications for stimulating a shift of the sector towards the principles of sustainable intensification are significant for stakeholders in both Asia and Europe. The EU, recognising the deficit between local production and consumption, currently supports the trade and has developed a system for health and safety quality assurance through its RAFFS system. Longer term, it also seeks to ensure that a level playing field for imported and locally produced food be developed within the EU (European Communities 2009). Currently a wide range of private sector actors are also involved in the governance of the trade including private standards organisations and seafood buyers representing retail and food service operators. Arguably their participation has been a disruptive force that has accelerated the pace of change towards more market orientated governance; an opposing view is that they have caused consumer confusion and added unnecessary cost. Such diversity however could be interpreted as a component of multiple approaches that are a key pillar of SI, and the continued involvement of a variety of players likely to promote creative tension and positive competition between them.

Ensuring that SI is better understood by choice editors and consumers is a clear priority for both Governments and other players. The complexity of the required messaging will, however, be a challenge especially given the continuum between ‘sustainable intensification’ and simple ‘intensification’. Determination of what trade-offs between the major pillars are acceptable, and which are not will require both local and validated scientific knowledge. For example, the strong and mainly positive links that characterise seafood exports and local nutrition and livelihoods need to be better understood and acknowledged. Support is required for the Asian aquaculture sector, in all its diversity, to develop and communicate its own narrative more effectively. Why are exotic species sometimes appropriate for farming, even in landscape systems? How can imported feed ingredients be used to enhance performance of low yielding systems and how are global impacts being reduced?

Such information should feed into better consumer information and more accessible knowledge for choice editors. The diversity of systems, species and their management will require careful, but transparent, translation from an SI perspective. This could be informed by measures that already established especially if the EU further refined its Country of Origin labelling requirements and the RAFFS process, which currently has significant limitations (Newton et al in preparation). For example, it could also ensure that all imported farmed seafood had smart labelling through which location of production, production system and other SI descriptors can be identified by consumers and choice editors. Such labels could feasibly be linked to web-based, accessible information for interested consumers. It could also expand the EU Protected Name Scheme, that encourages and supports food provenance in the EU, to Asian producers, that adopt and implement SI usually based on discrete, geographically clusters of production that are dependent on the same resource base.

Considering aquaculture as part of the broader seafood system and integral to food systems is long overdue in policy terms. A focus on delivery of quality human nutrition would sharpen analysis of environmental costs, both locally and globally. This is beginning to develop for food systems in general at a strategic level following food futures dialogues over recent years and trends in academic research but with a few exceptions has usually ignored fish (e.g. Roos et al, 206, 2017). A lack of nutrition-specific indicators for SDG14 (Life under water), in contrast to numerous environmental and social development indicators, has led to seafood being ignored in high profile global nutrition reporting. This state of affairs need to be urgently corrected by policy makers.

Our analysis has suggested that SI cannot be assessed on the farm alone but requires a comprehensive value chain approach, preferably integrated and informed by Life Cycle Assessment and other approaches to assess overall environmental and social impacts. Although this has been recognised by certification and assessment organisations, standardisation has proved a challenge and these approaches have yet to be integrated into most sustainability metrics. LCA is a versatile tool which is used in many instances for which different approaches are required. However, if LCA is to be used to benchmark products, a set of standardised approaches is required beyond those offered by the usual ISO 14040 and 14044 standards (ISO 2006a and 2006b). Some fundamental issues remain to be resolved, particularly around the functional unit for livestock, allocation of impacts between co-products and a move to these being defined in terms of nutritional benefit would represent major progress. Different practitioners are a long way from agreeing on best approaches and clear consensus is required on a number of issues to direct best practice before LCA can be used as a benchmarking tool (e.g. Pelletier and Tydemers 2011, MacKenzie et al 2017, ANEC 2012)

The multiple approaches inherent to making progress towards SI suggest that policy support for both resource sparing and sharing could be prioritised. Closing the yield gap remains a major challenge, particularly for small holder farmers that lack access to key technologies and knowledge. One study showed that average yields for smallholder polycultures could be more than doubled once farmers understood and invested in locally available nutrients (Karim et al, 2011). Recognising the value of landscape systems and incentivising their development through SI will be highly context specific. The integration of aquaculture within natural aquatic ecosystems such has been demonstrated for mangrove-shrimp systems in the Mekong Delta (see above) is one example but also a precautionary tale of the challenge in terms of achieving both environmental benefits and livelihoods gains for local people.

10. Conclusions

SI is a useful lens for interpreting the challenges and opportunities for the trade in farmed seafood between Asia and Europe. Ensuring production and consumption of animal protein remains within sustainable limits will require a rapid movement towards incentives supporting SI rather than conventional intensification. Ensuring farmed seafood is positioned as part of broader food systems is a key part of this strategy. Farm-level SI could lead to higher value and more sustained trade demanding but profitable markets since key credence qualities could be protected or enhanced. It could also form the basis for standards developers wishing to embrace a more comprehensive view of sustainability since, necessarily, it is not limited to the production enterprise but rather embraces both a community (zonal) and value chain approach.

Pressures on water and land resources are forcing intensification and stimulating integration of aquaculture with other uses. The challenges of meeting energy and nutrient needs in the coming decades will stimulate emergence of ever more efficient systems but competitiveness with other sectors of food production will be critical as will differences in comparative advantage between the farmed seafood sectors in Asia and Europe. A key element in the evolution of current conventional intensive systems towards greater sustainability will be use of precision technology and management, complemented by selective breeding and closed-containment technology. Salmon and shrimp are furthest along this trajectory that would most likely favour larger operations. Lower cost models for precision approaches are required for smaller producers to remain competitive.

The current bias among policy makers and planners towards production needs to shift towards demand, informed by farmed seafood being part of broader food systems and nutritionally balanced diets: production and consumption need to be considered in tandem. The dynamics of global seafood markets makes such SI thinking critical, especially as the Asia-Europe trade is likely to diminish in relative importance as regional and global trade continue to expand. Purchasing power and comparative advantage of production and processing are likely to continue to evolve especially in fast growing economies where fish is a preferred animal source food and the value of the whole animal can be most efficiently exploited. Finally, communicating the stories around farmed seafood produced sustainably at distance from consumers is challenging but urgent. Developing authentic and appealing narratives of farming seafood, together with innovative and effective value chain governance, will support the sector moving towards SI.

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References

Alder J, Campbell B, Karpouzi V, Kaschner K, and Pauly D. 2008, Forage Fish: From Ecosystems to Markets, Annual Reviews in Environment and Resources, vol. 33, pp. 153-166.

Alexander, K., Gatward, I. Parker, A, Black, K Boardman, A. Potts, T. Thomson, E.2014. An assessment of benefits to Scotland of Aquaculture. Marine Scotland. http://www.gov.scot/Topics/marine/Publications/publicationslatest/farmedfish/AqBenefits

Ali, H, Rico, A, Murshed-e-Jahan, K & Belton, B 2016, 'An assessment of chemical and biological product use in aquaculture in Bangladesh' *Aquaculture*, vol 454, pp. 199-209. DOI: 10.1016/j.aquaculture.2015.12.025ASC. 2010. ASC Pangasius Standard. http://www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem14323.pdf . World Wildlife Fund.

Amaravathis, T.,Oparimalam, P.,PRemalatha, M Hemalatha, G.,Ganguli, AK.2016. Health hazard of women employed in small scale seafood processing units. Indian Journal of Geo-Marine Sciences (IJMS) 45, 04, 574-582

ANEC, 2012. ANEC Position: Environmental Assessment goes Astray: A Critique of Environmental Footprint Methodology and its Ingredients. ANEC-ENV-2012-G-008final. ANEC, Brussels, Belgium. 39pp.

Armitage, Derek; Marschke, Melissa 2013. Assessing the future of small-scale fishery systems in coastal Vietnam and the implications for policy ENVIRONMENTAL SCIENCE & POLICY 27 184-194

Arthur, R.I., Lorenzen, K., Homekingkeo, P.,Sidavong, K.,Sengvilaikham, B., Garaway, C,J. 2010. Assessing impacts of introduced aquaculture species on native fish communities:
Nile tilapia and major carps in SE Asian freshwaters. Aquaculture 299, 81–88

Asche, F. & Khatun, F., 2006. *Aquaculture: issues and opportunities for sustainable production and trade*, Geneva: International Centre for Trade and Sustainable Development (ICTSD). Available at: http://dspace.cigilibrary.org/jspui/handle/123456789/28104.

Asche , F., Roll , K.H., Sandvold, H.N. , Sørvig, A. & Zhang, D,J. 2013.Salmon aquaculture:larger companies and increased production. Aquaculture Economics & Management, 17:3, 322-339.

Asche, F.Bellemare, M.F., Roheim, C, Smith. M.D and Tverteras, S. 2015. Fair enough?Food security and the International trade of seafood. World Development 67,151–160.

Asche, |f, COJOCARU ,A.L and Roth,B,*in press* The development of large scale aquaculture

production: A comparison of the supply chains for chicken and salmon. Aquaculture

Ayer N W, Tyedmers P H, Pelletier N L, Sonesson U and Scholz A, 2007. Co-Product Allocation in Life Cycle Assessments of Seafood Production Systems: Review of Problems and Strategies. International Journal of Life Cycle Assessment, vol. 12, 7, pp 480-487

Badiola M, Basurko OC, Gabiña G and Mendiola D 2017. Integration of energy audits in the Life Cycle Assessment methodology to improve the environmental performance assessment of Recirculating Aquaculture Systems. Journal of Cleaner Production 157 pp 155-166. Elsevier.

Banchun, Y., 2012. An Assessment of Farmers' Strategies to Reuse and Renovate Abandoned Shrimp Ponds in Surat Thani Province, Thailand. MSc Thesis. Asian Institute of Technology, Thailand. 142pp.

Banhazi, T., Black, J., 2009. Precision livestock farming: a suite of electronic systems to ensure the application of best practice management on livestock farms. Aust. J. Multidiscip. Eng. 7 (1), 1–13.

Beddington, J. 2009. Food, energy water and the climate: A perfect storm of global events. Seen at (26/10/2013) http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf

Belton, B. & Little, D.C. 2011. Contemporary Visions for Small-Scale Aquaculture. In: Chuenpagdee, R. (ed.) Contemporary Visions for World Small-Scale Fisheries. Delft: Eburon. Chapter 9.

Belton, B., Bush, S.R. and Little, D.C. 2016 Aquaculture: Are farmed fish just for the wealthy?, Nature 538, 171

Belton, B. Boyd, K and Little D.C. 2009. Reassessing sustainable aquaculture through the lens of tilapia production in Central Thailand. Society and Natural Resources 22, 840-855.

Béne; C; Arthur; R.; Norbury, H.; Allison[4]; E.H Beveridge; M.;Bush, S.;Campling,L.;Leschen; W.;Little; D. ;Squires, D.; Thilsted, S.; Troell, M and Williams, M. 2016. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Development. 79: 177-196.

Bentsen, H,B.;Gjerde, B.:Eknath, A.E. Palada de Vera, M.S.;Velasco, R.R.; Danting,J.C.; Dionisio, E.E.; Longalong, F.M.;Reyes., R.A.;Abella, T.A.;Tayamen, M.M.; Ponzoni, R.W.2017. Genetic improvement of farmed tilapias: Response to five generations of selection for increased body weight at harvest in *Oreochromis niloticus* and the further impact of the project 468(1), 206-217

Berrill, I. 2013.Integrated sealice management. A Scottish persepective. (http://www.fhf.no/media/67858/scotland_-_ian_berril_-_scottish_salmon_producers__organisation.pdf

Besnier,F Glover, K.A. Lien,S., Kent,M., Hansen, M.M., Shen, X and Skaala, Ø. 2015.Identification of quantitative genetic components of fitness variation in farmed, hybrid and native salmon in the wild. Heredity 115, 47–55.

Beveridge, M.C.M., Phillips, M.J. and Macintosh, D.J., 1997. Aquaculture and the environment: the supply of and demand for environmental goods and services by Asian aquaculture and the implications for sustainability. *Aquaculture research*, *28*(10), pp.797-807.

Bogard, J.R.,Thilsted, S.H.,Marks, G.C. Wahab, M.A.,Hossain, M.A.R.,Jakobsen,J. and Stangoulis,J. 2015. Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes Journal of Food Composition and Analysis 42 120–133

Bogard, J.R., Marks, G.C.,Mamun, A. ,Thilsted, S.H., 2017.Non-farmed fish contribute to greater micronutrient intakes than farmed fish: results from an intra-household survey in rural Bangladesh Public Health Nutr. 20, 4, :702-711.

Brammer, H. 2004 Can Bangladesh Be Protected From Floods? The University Press Ltd, Dhaka

Branson, E. J. and Southgate, P. J. 2008. Introduction, in Fish Welfare (ed E. J. Branson), Blackwell Publishing Ltd, Oxford, UK. doi: 10.1002/9780470697610.ch

Bunting, S.W.; Mishra,R.; Smith, K.G & Ray,D. (2015) Evaluating sustainable intensification and diversification options for agriculture based livelihoods within an aquatic biodiversity conservation context in Buxa, West Bengal, India, International Journal of Agricultural Sustainability, 13:4, 275-293, DOI: 10.1080/14735903.2014.966530

Bunting, S.W.; Bosma, R.H.van Zwieten, P.A.H. & Sidik, A.S. (2013):Bioeconomic modelling of shrimp aquaculture strategies for the Mahakam Delta, Indonesia. Aquaculture Economics & Management, 17:1, 51-70

Buoro, M., Olden, J.D.; Cucherousset, J. 2016 Global Salmonidae introductions reveal stronger ecological effects of changing intraspecific compared to interspecific diversity.*ECOLOGY LETTERS* 19,11 1363-1371,

Chambers S, Lobb, A, Butler L T and Traill B W. 2008. The influence of age and gender on food choice: a focus group exploration. International Journal of Consumer Studies, 32, pp 356-365

Cook, S.,Silici, L.,Adolph, B. and Walker,S. 2015. Sustainable intensification revisited. IIED Issue Paper. IIED, London.

Dasgupta, S.; Hossain, M. M.; Huq, M.; Wheeler, D. 2014. *Facing the Hungry Tide : Climate Change, Livelihood Threats, and Household Responses in Coastal Bangladesh*. Policy Research Working Paper;No. 7148. World Bank Group, Washington, DC.

De Silva, S.S., 2012. Aquaculture: a newly emergent food production sector—and perspectives of its impacts on biodiversity and conservation. *Biodiversity and Conservation*, 21(12), pp.3187–3220. Available at: http://link.springer.com/10.1007/s10531-012-0360-9.

Diana, J.S. 2009. Aquaculture production and biodiversity conservation BioScience 59 (1): 27–38

Diana, J.S. et al., 2013. Responsible Aquaculture in 2050: Valuing Local Conditions and Human Innovations Will Be Key to Success. *BioScience*, 63(4), pp.255–262. Available at: http://www.jstor.org/stable/info/10.1525/bio.2013.63.4.5.

d'Orbcastel E, Blancheton J-P and Aubin J, 2009. Towards environmentally sustainable aquaculture: comparison between two trout farming systems using Life Cycle Assessment. Aquaculture Engineering, vol. 40, pp 113-119.

Edwards, P. 2014 Promising aquaculture practices for sustainable intensification. Aquaculture Asia 19, 4, 3-16.

Edwards, P., 2015. Aquaculture environment interactions: Past, present and likely future trends. *Aquaculture*, 447, pp.2–14. Available at: http://dx.doi.org/10.1016/j.aquaculture.2015.02.001.

Eufuma, 2015, The EU Fishmarket. Directorate-General for Maritime Affairs and Fisheries of the European Commission. 72 pp.

European Communities. 2009. The Rapid Alert System for Food and Feed of the European Union. 30 year of keeping consumers safe. Luxembourg: Office for Official Publications of the European Communities. 40 pp.

European Commission. 2013. Commission Regulation (EU) No 56/2013 of 16 January 2013 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies . http://www.eurl.craw.eu/img/page/Legislation/56-2013_EN.pdf. 14pp

FAO. 2016. *THE STATE OF WORLD FISHERIES AND AQUACULTURE 2016. CONTRIBUTING TO FOOD SECURITY AND NUTRITION FOR ALL.* ROME. 200 PP.

Foley, J. A., Ramankutty, N., Brauman, K. A., et al. (2011). Solutions for a cultivated planet. *Nature 478*(7369), 337-342. 786 doi: 10.1038/nature10452

Foresight. 2011. *The Future of Food and Farming. Final Project Report*. The Government Office for Science,London.

FAO, 2016. FishstatJ. Available at: http://www.fao.org/fishery/statistics/software/fishstatj/en.

FAO. 2016. Report of the Workshop on Increasing Public Understanding and Acceptance of Aquaculture – the role of truth, transparency and transformation, Vigo, Spain, 10–11 October 201, 53pp. FAO Rome.

Faruque, G. 2007. An exploration of impacts of aquaculture production and marketing on rural livelihoods in three regions in Bangladesh. University of Stirling. 319 pp.

Frozen Food Europe, 2016 Premium drives growth for UK frozen food http://www.frozenfoodeurope.com/premium-drives-growth-for-uk-frozen-ready-meals/ Accessed 5th January 2017

GAA. 2010, Aquaculture Facility Certification - Feed Mills Best Aquaculture Practice Certification Standards, Guidelines. Global Aquaculture Alliance, St. Louis, USA. 13pp.

Gale, J., Mulvaney , L. and Real, M. 2016 How antibiotic seafood from China ends up on your table https://www.bloomberg.com/news/features/2016-12-15/how-antibiotic-tainted-seafood-from-china-ends-up-on-your-table?cmpid=socialflow-twitter-business&utm_content=business&utm_campaign=socialflow-organic&utm_source=twitter&utm_medium=social

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Godfray, H.C.J., 2013. Sustainable intensification in agriculture: premises and policies. Science 341 (6141), 33–34.

Garnett, T. and Godfray, C. 2012a. *Sustainable intensification in agriculture: navigating a course through competing food system priorities*. Food Climate Research Network and the Oxford Martin Programme on the Future of Food. Oxford University, UK.

Garnett, T. and Godfray, C. 2012b. Sustainable intensification: defining terms. *Food Ethics* 7(2): 8–9

Garnett T, Röös E and Little D (2015). Lean, green, mean, obscene…? What is efficiency? And is it sustainable? Food Climate Research Network, University of Oxford.

Garnett, T. (2015). Gut feelings and possible tomorrows: (where) does animal farming fit? Food Climate Research Network, 794 University of Oxford, Oxford, UK.

Gjedrem, T., 2012. Genetic improvement for the development of efficient global aquaculture: A personal opinion review. *Aquaculture*, 344–349(44), pp.12–22. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0044848612001548.

Gjedrem, T., Robinson, N. & Rye, M., 2012. The importance of selective breeding in aquaculture to meet future demands for animal protein: A review. *Aquaculture*, 350–353, pp.117–129. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0044848612002128.

Globefish. 2017. China becomes largest Pangasius market in Asia.http://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/903636/

GlobalGAP. 2011. Control Points and Compliance Criteria: Compound Feed Manufacture, Code Ref: CFM 2.1 CPCC. GlobalGAP, Cologne, Germany. 35pp

Global Panel on Agriculture and Food Systems for Nutrition. 2016. Food systems and diets: Facing the challenges of the 21st century. London, UK.

Glover K, Pertoldi C, Besnier F, Wennevik V, Kent M, Skaala O (2013). Atlantic salmon populations invaded by farmed escapees: quantifying genetic introgression with a Bayesian approach and SNPs. BMC Genet 14: 74.

Golden, C.D., Allison*, E.H.,* Cheung*,W.W.L* Dey*, M.M.,* Halpern*, B.S.,* McCauley*, D.J.,*Smith*,M.,*Vaitla*, B.,*Zeller , D.*and* Myer, S.S. 2016 Nutrition: Fall in fish catch threatens human health *Nature* 534, 317–320

Gozlan, R. E. (2008), Introduction of non-native freshwater fish: is it all bad?. Fish and Fisheries, 9: 106–115

Ha, T.T.T. ; Van Dijk, H., and Bush, S.R. 2012. Mangrove conservation or shrimp farmer's livelihood? The devolution of forest management and benefit sharing in the Mekong Delta, Vietnam Ocean & Coastal Management 69, 185-193

Handisyde, N, Telfer,T.C. and Ross, L.G. 2016. Vulnerability of aquaculture-related livelihoods to changing climate at the global scale. Fish and Fisheries DOI: 10.1111/faf.12186

Henriksson P, Guinée J, Heijungs R, de Koning A, Green D, 2014a. A protocol for horizontal averaging of unit process data—including estimates for uncertainty. International Journal of Life Cycle Assessment, vol. 19, pp 429–436.

Henriksson P, Zhang W, Nahid S, Newton R, Phan L, Hai D, Zhang Z, Andong R, Jaithang J, Chiamanuskul K, Son V, Hien H, Haque M, Kruijssen F, Satapornvanit K, Nguyen P, Phan L T, Liu Q, Liu L, Wahab M, Murray F, Little D C, Guinée J. 2014b. Final LCA Case Study Report Primary Data and Literature Sources Adopted in the SEAT LCA Studies, SEAT Deliverable Ref: D 3.5. EU FP7 Funded Project 222889. Available at: http://media.leidenuniv.nl/legacy/d35-annexreport.pdf. 121pp

Henriksson PJG, Rico A, Zhang W, Nahid SA, Newton R, Phan LT, Zhang Z, Jaithiang J, Little DC, Murray FJ,Liu L, Liu Q, Haque MM, de Snoo GR, Heijungs R and Guinée JB. 2015. A relative comparison of Asian aquaculture products using statistically supported LCA. Environmental Science and Technology., 49, 14176−14183.

Herbert, RJH ; Humphreys, J ; Davies, CJ ; Roberts, C ; Fletcher, S ; Crowe, TP. 2016 Ecological impacts of non-native Pacific oysters (Crassostrea gigas) and management measures for protected areas in Europe Biodiversity and Conservation, 25,14 2835-2865

Hilborn, R; Branch, TA; Ernst, B; et al. 2003 State of the world's fisheries. Annual Review of the Environment and Resources 28, 359-399

Horvath, H., Angeletti,D., Nascetti, G.,) and Carere, C. 2013 Invertebrate welfare: an overlooked issue. Ann Ist Super Sanità . 49,1: 9-17 DOI: 10.4415/ANN_13_01_04

Hossain, M.A., Sarker, A.K. , Amin, M.N. ,Hossain M.M. and Miah. M.S. 2016. Development and performance evaluation of sludge remover for intensive aquaculture. Aquaculture Engineering 74, 62-79.

Huysveld, S., Schaubroeck, T., De Meester, S., Sorgeloos, P., Van Langenhove, H., Van Linden, V., Dewulf, J., 2013. Resource use analysis of pangasius aquaculture in the Mekong Delta in Vietnam using exergetic life cycle assessment. J. Clean. Prod. 51, 225e233.

International Food Policy Research Institute. 2016. *Global Nutrition Report 2016: From Promise to Impact: Ending Malnutrition by 2030*. Washington, DC.

Iguacel, I., Fernández-Alvira, J.M., Bammann, K., De Clercq, B., Eiben, G., Gwozdz, W., Molnar, D., Pala, V., Papoutsou, S., Russo, P., Veidebaum, T., Wolters, M., Börnhorst, C. and Moreno, L.A. (2016) 'Associations between social vulnerabilities and dietary patterns in European children: the Identification and prevention of Dietary- and lifestyle-induced health EFfects In Children and infantS (IDEFICS) study', *British Journal of Nutrition*, 116(7), pp. 1288–1297. doi: 10.1017/S0007114516003330

ISO, 2006a. Environmental Management - life cycle assessment - principles and framework (ISO 14040:2006). ISO. Geneva, Switzerland. 20pp.

ISO, 2006b.Environmental Management - life cycle assessment - requirements and guidelines (ISO 14044:2006). ISO. Geneva, Switzerland. 45pp.

Iversen, A., Andreassen, O., Hermansen, O., Larsen, T.A., & Terjesen, B.F. 2013. Oppdrettsteknoligi og konkurransepoisisjon. Nofima Rapport 32/2013

Herrero, M., Thornton, P.K., Notenbaert, A.M., et al., 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science. 327(5967):822-5.

Hishamunda, N., Bueno, P., Menezes, A.M., Ridler, N., Wattage, P. & Martone, E. 2014. Improving governance in aquaculture employment: a global assessment.FAO Fisheries and Aquaculture Technical Paper No. 575. Rome, FAO. 48 pp.

Huysveld S,., Schaubroeck T, De Meester, S, Sorgeloos,P.,Van Langenhove, H., Van linden, V. and Dewulf, J. 2013.Resource use analysis of Pangasius aquaculture in the MekongDelta in Vietnam using Exergetic Life Cycle Assessment. Journal of Cleaner Production 51 225-233

Immink, A. & Clausen, J. 2017. Aquaculture Certification and Zonal Management. In J. Aguilar-Manjarrez, D. Soto & R. Brummett. *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. Full document,* pp. 87–94. Report ACS113536. Rome, FAO, and World Bank Group,Washington, DC. 395 pp.

Karim, M., Little, D.C., Kabir, M.S., Verdegem, M.J.C., Telfer, T. and Wahab, M.A. (2011) Enhancing benefits from polycultures including tilapia (Oreochromis niloticus) within integrated pond-dike systems: a participatory trial with households of varying socio-economic level in rural and peri-urban areas of Bangladesh. Aquaculture 314, 1-4225-235.

Karim M, Sarwer RH, Brooks AC, Gregory R, Jahan KM, Belton B (2012) The incidence of suspected white spot syndrome virus in semi intensive and extensive shrimp farms in Bangladesh: implications for management. Aquaculture Research 43:1357–1371.

Kim,R.B. 2012. Determinants of brand equity for credence goods: Consumers' preference for country origin, perceived value and food safety Agric. Econ. – Czech, *58*,7, 299–307.

Kulawik, P.; Migdał, W, Tkaczewska,J. and Özoğul, F. 2016 Assessment of Color and Sensory Evaluation of Frozen Fillets from Pangasius Catfish and Nile Tilapia Imported to European Countries. International Journal of Food Properties 19 , 7.

Kulawik P., Migdał W., Tkaczewska J., Gambuś F., Szczurowska K., Özoğul F. (2016). Nutritional composition of frozen fillets from Pangasius catfish (*Pangasius hypophthalmus)* and Nile tilapia *(Oreochromis niloticus)* imported to European countries, Annals of Animal Science, DOI: 10.1515/aoas-2016-0012 .

Lam, M. E.; Pitcher, T. J.2012 The ethical dimensions of fisheries. Current opinion in environmental sustainability, 4,3, 364-373 .

Lam, M.E. 2016 The Ethics and Sustainability of Capture Fisheries and Aquaculture. Journal of Agricultural and Environmental Ethics, 29 ,1,35-65

Lassoued, R and Hobbs, J.E. 2015. Consumer confidence in credence attributes: The role of brand trust Food Policy 52 99–107.

Lebel,L.,Nguyen, H.Ti,Saengnoree, A.,Pasong, S.,Buatama , U.and Le,K.T. 2002. Industrial Transformation and Shrimp Aquaculture in Thailand and Vietnam: Pathways to Ecological, Social, and Economic Sustainability? Ambio, 31 4, 311-323 Ambio

Leclercq, E [1]; Graham, P [1]; Migaud, H. 2015. Development of a water-stable agar-based diet for the supplementary feeding of cleaner fish ballan wrasse (Labrus bergylta) deployed within commercial Atlantic salmon (Salmo salar) net-pens. Animal Feed Science and Technology, 208, 98-106.

Lee, J.Gereffi, G. and Beauvaisc. 2012. Global value chains and agrifood standards: Challenges and possibilities for smallholders in developing countries. PNAS, 109,311, 2326–12331

Leprieur, F., Brosse, S., Garcia-Berthou Oberdorff, T., Olden J.D., Townsend, C.R. 2009. Scientific uncertainty and the assessment of risk posed by non-native freshwater fishes. Fish and Fisheries 10 1 88-97

Little, D.C., Bush, S.R., Belton, B. Phuong, N.T., Young, J.A. and Murray, F.J. 2012. Whitefish wars: Pangasius, politics and consumer confusion in Europe. Marine Policy 36: 738-745

Little, D.C., Barman, B.K., Belton, B., Beveridge, M.C., Bush, S.J., Dabaddie, L., Demaine, H., Edwards, P., Haque, M.M., Kibria, G., Morales, E., Murray, F.J., Leschen, W.A., Nandeesha, M.C., & Sukadi, F. 2012. Alleviating poverty through aquaculture: progress, opportunities and improvements, *In* R.P. Subasinghe, J.R. Arthur, D.M. Bartley, S.S. De Silva, M. Halwart, N. Hishamunda, C.V. Mohan & P. Sorgeloos, eds. *Farming the Waters for People and Food*. Proceedings of the Global Conference on Aquaculture 2010, Phuket, Thailand. 22–25 September 2010. pp. 719–783. FAO, Rome and NACA, Bangkok

Little, D.C. , Newton, R.W and Beveridge, M.C.M. 2016. Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. Proceedings of the Nutrition Society, 75, 274–286

Little, D.C. and S.W. Bunting. 2016 Aquaculture Technologies for Food Security. Chapter 5 In Madramootoo, C. (ed.) Emerging Technologies for Promoting Food Security Elsevier.http://dx.doi.org/10.1016/B978-1-78242-335-5.00005-6

Lorenzen, K., Beveridge, M. C.M. and Mangel, M. (2012), Cultured fish: integrative biology and management of domestication and interactions with wild fish. Biological Reviews, 87: 639–660. doi:10.1111/j.1469-185X.2011.00215.x

Mackenzie S, Leinonen I, Kyriazakis I (2017) The need for co-product allocation in the life cycle assessment of agricultural systems—is biophysical allocation progress? Int J Life Cycle Assess 22:128–1

Madin, E.M.P. and Macreadie , P.I. 2015. Incorporating carbon footprints into seafood sustainability certification and eco-labels. Marine Policy 57 178–181.

Mamun, A.A. 2016. Shrimp-prawn farming in Bangladesh: Impacts on livelihoods, food and nutritional security. PhD Thesis 334pp.Univeristy of Stirling, Stirling , UK.

Marques, A Rodriguez-Mozaz, S. Granby, K. 2017 Safety assessment of contaminants of emerging concern in seafood: Contributions of the ECsafeSEAFOOD project Food and Chemical Toxicology 104 1-2.

Martinez-Porchas, M. & Martinez-Cordova, L.R., 2012. World aquaculture: environmental impacts and troubleshooting alternatives. *The Scientific World Journal*, 2012, p.389623. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3353277%7B&%7Dtool=pmcentrez%7B&%7Drendertype=abstract.

MILSTEIN, A. 1992. ECOLOGICAL ASPECTS OF FISH SPECIES INTERACTION IN POLYCULTURE PONDS. HYDROBIOLOGIA, 231, 3,177-186.

MUELLER, N.D,GERBER, J.S.· JOHNSTON,M.[1]RAY, D.K, RAMANKUTTY, N.FOLEY, J.A. 2012 Closing yield gaps through nutrient and water management NATURE 490 254 -257.

Mungkung, R. & Gheewala, S.H., 2007. Use of life cycle assessment (LCA) to compare the environmental impacts of aquaculture and agri-food products. In D. M. Bartley et al., eds. *Comparative assessment of the environmental costs of aquaculture and other food production sectors: methods for meaningful comparisons.FAO/WFT Expert Workshop. 24-28 April 2006, Vancouver, Canada. FAO Fisheries Proceedings. No. 10. Rome,*. Rome: FAO, pp. 87–96. Available at: ftp://ftp.fao.org/docrep/fao/010/a1445e/a1445e06.pdf.

Murray F, Bostock J & Fletcher D (2014) Review of recirculation aquaculture system technologies and their commercial application. Highlands and Islands Enterprise. University of Stirling Aquaculture.

Murk, A. J., Rietjens, I. M.C.M. and Bush, S. R. (2016), Perceived versus real toxicological safety of pangasius catfish: a review modifying market perspectives. Rev Aquacult. doi:10.1111/raq.12151

Murray, F.J. 2013 SEAT Action Research with Small and Medium Enterprises (SMEs); Organic Shrimp Farming in Bangladesh. SEAT news letter 19 July 2013 http://WWW.SEATGlobal.eu

Naylor, R.L., Goldburg, R.J., Mooney, H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Primavera, J. and Williams, M., 1998. Nature's subsidies to shrimp and salmon farming. *Science*, *282* (5390), pp.883-884.

Naylor R, Hardy R, Bureau D, Chiu A, Elliot M, Farrell A, Forster I, Gatlin D, Goldburg R, Hua K and Nichols P. 2009. Feeding aquaculture in an era of finite resources. Proceedings of the National Academy of Sciences, vol. 106, 36, pp 15103-15110.

Needham, S. & Funge-Smith, S. J. (2014) “The consumption of fish and fish products in the Asia-Pacific region based on household surveys”. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand . RAP Publication 2015/12. 87pp

New, M.B., 2003. Responsible aquaculture: is this a special challenge for developing countries? In *World Aquaculture 2003*. Salvador, Brazil: World Aquaculture Society, p. 70. Available at: http://www.aquaculturewithoutfrontiers.org/wp-content/uploads/2011/09/2003-WAS-SALVADOR-KEYNOTE-MICHAEL-NEW.pdf.

Newton, R Telfer, T and Little, D.C. (2014*)* Perspectives on the utilisation of aquaculture co-product in Europe and Asia: prospects for value addition and improved resource efficiency Critical Reviews in Food Science and Nutrition 54:4, 495-510.

Nhu, T.T., Schaubroeck,T., De Meester, S., Duyvejonck, M.,Sorgeloos, P., Dewulf,J. Resource consumption assessment of Pangasius fillet products from Vietnamese aquaculture to European retailers. Journal of Cleaner Production 100, 170-178

Nhu, T.T.Schaubroeck, T. Henriksson, P.J.D. Bosma, R., Sorgeloos, P., Dewulf, J. 2016. Environmental impact of non-certified versus certified (ASC) intensive Pangasius aquaculture in Vietnam, a comparison based on a statistically supported LCA Environmental Pollution 219, 156-165

Oita, A.,Nagano, I., and Matsuda, H. 2016. An improved methodology for calculating the nitrogen footprint of seafood. Ecological Indicators,60, 1091–1103

Pantazidou, M. and Gaventa, J. 2016. Challenging the Asymmetries of Power: A Review of the Institute of Development Studies (IDS) Contribution . IDS Bulletin. 47, 2. 89-104

Pappalardo,A.M. and Ferrito, C. 2015. DNA barcoding species identification unveils mislabeling of processed flatfish products in southern Italy markets Fisheries Research, 164, 153–158.

Pelletier N L, and Tyedmers PH, 2007. Feeding farmed salmon: is organic better? Aquaculture. Vol. 272, 399-416.

Pelletier N L, and Tyedmers P H, 2010. Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. Journal of Industrial Ecology, vol. 14, pp 467-481.

Pelletier N L, Tydmers P H, Sonesson U, Scholz A J, Ziegler F, Flysjo A, Kruse S A, Cancino B and Silverman H. 2009. Not all salmon are created equal: Life Cycle Assessment (LCA) of global salmon farming systems. Environmental Science Technology, vol. 43, pp. 8730-8736.

Pelletier N L, and Tyedmers P H, 2011. An ecological economic critique of the use of market information in Life Cycle Assessment research. Journal of Industrial Ecology, vol. 15, 3, pp 342-354.

Pitcher, T, J.; Lam, M. E. 2015 Fish commoditization and the historical origins of catching fish for profit. Maritime studies, 14, 2. DOI 10.1186/s40152-014-0014-5

Phong L T, de Boer I J M, and Udo H M J, 2011. Life cycle assessment of food production in integrated agriculture–aquaculture systems of the Mekong Delta. Livestock Science, vol. 139, 1-2, pp 80-90.

Ponte, S Kelling, I., Sau Jesperson, K and Kruijssen, F 2014 The Blue revolution in Asia: Upgrading and governance in Value chains. World Development 64, 52-64.

Pretty, J. 1997. The sustainable intensification of agriculture. *Natural Resources Forum* 21(4): 247–256.

Primavera J H 2008 Socio-economic impacts of shrimp culture. Aquaculture Research, 28, 10. 815-827

Quinn I. 2012. Frustrated Tesco ditches eco-labels. Groc:4.

Quinton C.D., Kause, A, Koskela, J, Ritala, O. 2007. Breeding salmonids for feed efficiency in current fishmeal and future plant-based diet environment. Genetics selection evolution, 39,4, 431-446

Raghavan, S. and Kristinsson, H. G. (2009). ACE-inhibitory activity of tilapia protein hydrolysates. Food Chem. 117:582–588.

Rahman, MM (Rahman, Mohammad Mustafizur)[1]; Verdegem, M (Verdegem, Marc)[2

2010. Effects of intra- and interspecific competition on diet, growth and behaviour of Labeo calbasu (Hamilton) and Cirrhinus cirrhosus (Bloch) APPLIED ANIMAL BEHAVIOUR SCIENCE 128, 1-4 , 103-108

Reardon, T., Crawford, E., Kelly, V. and Diagana, K. 1995. Promoting farm investment for sustainableintensification of African agriculture. MSU International Development Paper #18. Michigan State University,Michigan

Roberts, C.A., Newton, R.W., Bostock, J.C, Prescott, S.G, Honey, D.J., Telfer, T.C., Walmsley, S.F., Little, D.C, Hull, S.C. 2015. A Risk Benefit Analysis of Mariculture as a means to Reduce the Impacts of Terrestrial Production of Food and Energy. A study commissioned by the Scottish Aquaculture Research Forum (SARF). http://www.sarf.org.uk/

Robinson T P, Thornton P K, Franceschini G, Kruska R L, Chiozza F, Notenbaert A, Cecchi G, Herrero M , Epprecht M, Fritz S, You L, Conchedda G and See L. 2011. Global livestock production systems. Food and Agriculture Organization of the United Nations (FAO), Rome and International Livestock Research Institute (ILRI), 152 pages.

Roheim,C.A.,Sudhakaran, P.O. & Durham, C.A. 2012 .Certification of shrimp and salmon for best management practices:Assessing consumer preferences I Rhode Island Aquaculture Economics & Management, 16:3, 266-286.

Roos, E. 2017 Greedy or needy? Land use and climate impacts of food in 2050 under different 1 livestock futures. Global Environmental Change. 47.1-12.

Roos, N., Wahab, M., Hossain, M.A.R., Thilsted, S.H., 2007. Linking human nutrition and fisheries: incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. Food and Nutrition Bulletin 28 (2), S280–S293.

Ross, L.G., Telfer, T.C., Falconer, L., Soto, D. & Aguilar-Manjarrez, J., eds. 2013. Site selection and carrying capacities for inland and coastal aquaculture. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6–8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 46 pp.

Sander, M., Heim, N ,Kohnle, Y.2016   Label awareness: How closely does the consumer look? - An analysis of consumers' label awareness with particular regard to the food sector. BERICHTE UBER LANDWIRTSCHAFT , 94,2,

Schmidt J H. 2010. Comparative life cycle assessment of rapeseed oil and palm oil. International Journal of Life Cycle Assessment, vol15, pp 183-197

Setboonsarng, S. (1993) Evolution of Freshwater Aquaculture in Northeast Thailand: Growth of a New Technology.International Symposium of Socio Economics of Aquaculture. Kee Lung, Taiwan ROC.

Shelton, W.L. & Rothbard, S., 2006. Exotic species in global aquaculture-A review. *The Israeli Journal of Aquaculture – Bamidgeh*, 58(1), pp.3–28. Available at: https://evols.library.manoa.hawaii.edu/handle/10524/19156.

Sorgeloos, P., 2001. Technologies for sustainable aquaculture development, plenary lecture 11. In: Subasinghe, R.P., et al. (Eds.), Aquaculture in the Third Millennium, Technical Proceedings of the Conference on Aquaculture in the Third Millennium. NACA, Bangkok, pp. 23–28 (FAO, Rome).

Steinberg.K, 2012. Socioconomic impacts of shrimp farming in Bangladesh. MSc Thesis. 51 pp University of Stirling.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and De Haan, C., 2006. *Livestock's long shadow* (p. 229). Rome: FAO.

Sustainable Development Knowledge Platform. 2016. SDG14, Life Under the water. https://sustainabledevelopment.un.org/sdg14 (seen at 4th September 2017)

Tacon and Metian. 2015. Feed matters: satisfying the feed demand of aquaculture. Reviews in Fisheries Science and Aquaculture. Vol 23, pp1-10.

The Royal Society. 2009. *Reaping the Benefits:Science and the Sustainable Intensification of GlobalAgriculture.* RS Policy Document 11/09. The Royal Society, London.

The Positive Deviance Initiative. (2010). *Basic field guide to thepositive deviance approach*. Retrieved from http://www.positivedeviance.org/pdf/Field%20Guide/FINALguide17092017.pdf

Thorkelsson, G. and Kristinsson, H. G. (2009). Bioactive Peptides fromMarine Sources. State of Art. Report to the NORA fund. 14-09. Matis Food Research, Innovation and Technology, Reykjav´ık, Iceland.

Tlusty, M.F.,Hardy , R. and Cross, S.F. 2011. Limiting Size of Fish Fillets at the Center of the Plate Improves the Sustainability of Aquaculture Production *Sustainability*, *3*, 957-964

Tort, L.; Balasch, J.C. and S. Mackenzie. 2003. Fish immune system. A crossroads between innate and adaptive responses Inmunología 22, (3), 277-286.

Trifkovic, N. 2014 Certified standards and vertical coordination in aquaculture: The case of pangasius from Vietnam

Troell, M. Naylor, ,R.L., Metian,M,; Beveridge,, M; Tyedmers; P,Folke, C.; Arrowf, K.J.;Barrett, S.; Crépin, ,A.S.;Ehrlich P.R.; Gren, A.; Kautsky, ,N.; Levinj, S.A. Nyborg, K.; Österblom, H.; Polasky,, S.; Scheffer, ,M. Walker, B.H., Xepapadeas, T and Zeeuw, A.D.2015. Does aquaculture add resilience to the global food system? www.pnas.org/cgi/doi/10.1073/pnas.1404067111

Samuel-Fitwi B, Nagel F, Meyer S, Schroeder JP and Schulz C. 2013. Comparative life cycle assessment (LCA) of raising rainbow trout (*Oncorhynchus mykiss*) in different production systems. Aquacultural Engineering 54 pp 85–92. Elsevier.

Schubert, W.R. 2012. Fishing for NTBs: The Catfish Wars as a Rent-Seeking Problem Journal of Macromarketing 32(1) 121-136

Summerfelt, S., Waldrop, T., Good, C., Davidson, J., Backover, P., Vinci, B. & Carr, J. 2013. Freshwater growout trial of St John River strain Atlantic salmon in a commercial-scale land-based, closed-containment System. The Conservation Fund, 52pp.

Treasurer, J.W. 2012. Diseases of north European wrasse (Labridae) and possible interactions with cohabited farmed salmon, Salmo salar L. Jounal of Fish Diseases, 35, 8, 555-562.

TUŠELJAK N, DUTIL L, RAJIĆ A, UHLAND FC, MCCLURE C, ST-HILAIRE S, REID-SMITH RJ, MCEWEN,SA. 2013. Antimicrobial use and resistance in aquaculture: findings of a globally administered survey of aquaculture-allied professionals. Zoonoses Public Health. 60,6, 426-36.

UNGER, J ; SCHUMANN, M. ; BRINKER, A. 2015. FLOATING FAECES FOR A CLEANER FISH PRODUCTION. AQUACULTURE ENVIRONMENT INTERACTIONS, 7, 3, 223-238.

PIJL, W. VAN DER, 2014. AN UPDATE OF SHRIMP AND PRAWN SUPPLY CHAIN INITIATIVES IN BANGLADESH; RECOMMENDATIONS FOR INCLUSIVE SHRIMP SUPPLY CHAIN DEVELOPMENT FOR THE STDF PROJECT. WAGENINGEN, LEI WAGENINGEN UR (UNIVERSITY & RESEARCH CENTRE), LEI 14-028. 32 PP.

UN, 2016. UNITED NATIONS COMMODITY TRADE STATISTICS DATABASE. *UNITED NATIONS COMMODITY TRADE STATISTICS DATABASE*. AVAILABLE AT: HTTPS://COMTRADE.UN.ORG/ [ACCESSED JANUARY 1, 2017].

Watterson, A., Little, D., Young, J.A., Murray, F.J., Doi, L., Boyd, K., Azim, E. 2012 Scoping a Public Health Impact Assessment of Aquaculture with Particular Reference to Tilapia in the UK. Public Health. 2012: 18p. http://dx.doi.org/10.5402/2012/203796.

Warren-Myers F, Dempster T, Fjelldal PG, Hansen T, Swearer SE.2015. An Industry-Scale Mass Marking Technique for Tracing Farmed Fish Escapees. PLoS ONE 10(3): e0118594. doi:10.1371/journal.pone.0118594

Welcomme, R.L. & Bartley, D.M. 1998. An evaluation of present techniques for the enhancement of fisheries.*In* T. Petr, ed. *Inland _shery enhancements.* FAO Fisheries Technical Paper No. 374. Rome, FAO. 463 pp. (also available at www.fao.org/docrep/005/w8514e/w8514e00.htm).

Xian, Z. 2016. A study of carp production and consumption in Hubei Province, China /MSc Thesis, University of Stirling 49p.

Zhang, W, Henriksson, P.Guinée, J,Murray, F.J. , Liu, Q. and Little, D.C Comparative Life cycle assessment (LCA) of tilapia, pig and integrated tilapia-pig farming systems in China

Zhang, W. et al., 2015. A comparative analysis of four internationally traded farmed seafood commodities in China: domestic and international markets as key drivers. *Reviews in Aquaculture*, 0, pp.1–22. Available at: http://doi.wiley.com/10.1111/raq.12110.

Zhao, X.,Finlay,D.and Kneafsey,M. 2014. The effectiveness of contemporary Geographical Indications (GIs) schemes in enhancing the quality of Chinese agrifoods – Experiences from the field .Journal of Rural Studies 36 , 77-86

List of Figures

Table 1 Intensification indicators for four pond-farmed aquatic commodity species groups across Asia 2010

Indicator	**Country**	**Shrimp**	**Prawn**	**Tilapia**	**Pangasius**
Primary spp.	Bangladesh	*P. monodon* (PM)	*M. rosenbergii*	*O. niloticus*	*P. hypophthalmus*
	Vietnam	*P. vannamei / P. monodon*	*M. rosenbergii*	*O. niloticus*	*P. hypophthalmus*
	China	*P. vannamei/ P. japonicas* (PJ)	*M. rosenbergii*	*O. niloticus*	NA
	Thailand	*P. vannamei* (PV)	*M. rosenbergii*	*O. niloticus*	*P.hypophthalmus*
Average Pond Stocking Density (Seed, PL/m2) [STDEV, n]	Bangladesh	3.9 [3.5, 252]	1.9 [1.3, 240]	7.6 [3.9/ 5]	4.4 [2.3/ 85]
	Vietnam	PV: 83.7 [20, 30] PM: 12.6 [13/ 194]	3-10 [0, 1]	No data	80.5 [18.2, 201]
	China	PV: 179.6 [133, 164] PJ: 16.25 [12.2/ 10]	No data	2.7 [1.2/ 201]	NA
	Thailand	62.8 [29.5, 213]	54.3 [6.6, 2]	17.2 [58.2, 166]	0.7 [0.7, 4]
Pond Polyculture	Bangladesh	carps, SIS, tilapia, prawn	carps, SIS, shrimp	carps, SIS, pangasius	Carps, SIS, tilapia
	Vietnam	PV: Mono PM: Mono/ mud-crab, SIS	Mono	No data	Mono
	China	PV: Mono/ tilapia, other spp.	No data	2ndry sp. with carps	NA

	Thailand	Mono	No data	Mono/ other spp.	Other spp.
Production Systems	Bangladesh	Dyke ponds	Dyke ponds	Excavated ponds	Excavated ponds
	Vietnam	Dyke & excavated ponds	Dyke & excavated ponds	No data	Deeper excavated ponds
	China	Dyke & excavated ponds	Dyke & excavated ponds	Excavated ponds, cages, reservoirs	NA
	Thailand	Excavated ponds	Excavated ponds	Excavated ponds, cages	Excavated ponds
Average Grow-out Pond Area (Ha) [STDEV, n]	Bangladesh	8.07 [14.5/172]	0.41 [0.34/ 160]	No data	1.46 [3.05/ 89]
	Vietnam	PV: 0.46 [0.53/ 22] PM: 1.07 [0.8/ 36]	0.75 [0/ 1]	No data	0.45 [0.4/ 210]
	China	0.41 [0.35/ 166]	No data	1.4 [2.58/ 199]	No data
	Thailand	0.62 [0.32/ 185]	No data	1 [0.87/ 155]	0.26 [0.12/ 2]
Maximum Pond Water Depth (m)	Bangladesh	1.15 [0.52/ 172]	2 [0.74/ 160]	No data	1.65 [0.53/ 90]
	Vietnam	1.33 [0.39/ 164]	1.2m [0/ 1]	No data	4.1 [0.76/ 210]
	China	1.9 [0.62/ 165]	No data	3.25 [1.14/ 199]	NA
	Thailand	2 [0.5/ 185]	No data	1.86 [0.54/ 191]	No data
Improved Seed	Bangladesh	Wild broodstock &/ or PLs	Domesticated and wild broodstock &/ or PLs	Domesticated broodstock / sex reversal	Domesticated broodstock
	Vietnam	PV: SPF & selected traits	Domesticated broodstock	Domesticated broodstock /	Domesticated broodstock

		PM: Wild broodstock		sex reversal	
	China	PV: SPF & selected traits	No data	Domesticated/ sex reversed	NA
	Thailand	PV: SPF & selected traits	Domesticated	Domesticated/ sex reversed	Domesticated
Disease control	Bangladesh	Extensive to semi-intensive culture in low-lying flood plains	Extensive to semi-intensive culture in low-lying flood plains	Low water exchange/ groundwater use	Low water exchange/ groundwater, nursery ponds
	Vietnam	PV: SPF & selected traits PM: lower stocking density	Side lining of ponds	Shift from river cages to ponds	Shift from river cages to ponds, chemotherapeutants
	China	‘Closed’ production in elevated ponds or lower stocking density in ‘low-level ponds, predator nets	No data	Low water exchange/ use of groundwater	NA
	Thailand	‘Closed’ production in elevated ponds using with dedicated treatment ponds, predator nets	No data	Low water exchange, in-situ water treatment, some nursery ponds	No data
Aeration	Bangladesh	None	None	None	None
	Vietnam	PV: Permanent PM: None or partial	None	None	Partial
	China	PV: Permanent	None	None or partial	NA

		PJ: None			
	Thailand	Permanent	None	None	None
Feeds	Bangladesh	None or on-farm	Apple snail, formulated	On-farm, formulated	On-farm & formulated
	Vietnam	Mostly formulated	Apple snail, formulated	On-farm, formulated	Mostly formulated
	China	Mostly formulated	No data	Low cost livestock feed	NA
	Thailand	Formulated	No data	Low cost livestock feed	No data
Fertilisers	Bangladesh	TSP, urea, cow dung	TSP, Urea, Potash, NPK	No data	(Lime)
	Vietnam	NPK, Urea & commercial organic	(Lime, dolomite)	No data	(Lime)
	China	NPK, Urea, TSP & commercial organic	No data	Pig poultry manure, night soil	NA
	Thailand	Urea, NPK & commercial organic	No data	Urea, poultry manure	No data
Production Scheduling	Bangladesh	Staggered (stocking & harvest)	Staggered (stocking & harvest)	Batch	Batch
	Vietnam	PV: Batch PM: Batch & staggered	Batch	No data	Batch
	China	PV: Batch	No data	Batch	NA

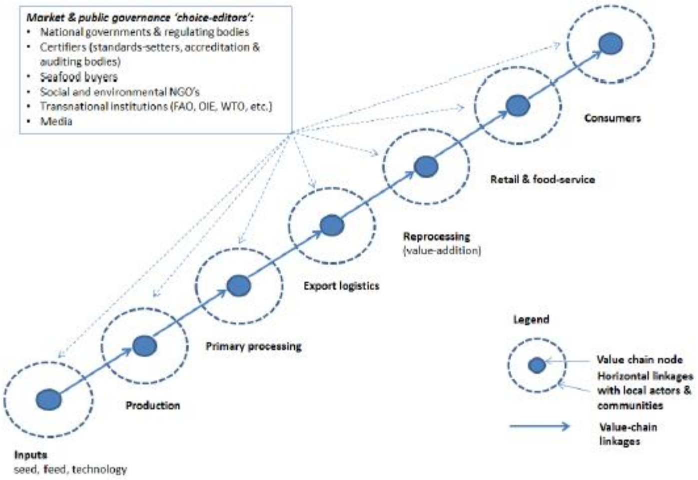
	Thailand	Batch	No data	Batch	No data
Cycle duration (Months)	Bangladesh	PM: 214 [86 172]	230 [35,160]	No data	237 [73, 77]
	Vietnam	PV: 98 [30,30] PM: 165 [60, 200]	190-210 (0,1)	No data	214 [43,212]
	China	PV: 87 [15,33]	No data	215 [76, 205]	NA
	Thailand	PV: 99 [18,211]	No data	254 [74 153]	246 [39, 5]
Average Yield Main Cycle (Kg/ha/cycle) [ST DEV, n]	Bangladesh	284 [255,170] Other spp. 253 [281,108	217 [197, 159] Other spp. 360 [277, 156]	No data	37,891 [25,937, 81] Other spp. 5,517 [7119, 119]
	Vietnam	PV: 7,808 [5276, 29] PM: 1,953 [3,367, 185]	1,000 [0,1]	No data	284,580 [217,110, 208]
	China	PV: 13,437 [12,375,31]	No data	16,579 [14,579, 18] Carps: 2,347 [2,318, 4]	NA
	Thailand	12,747 [112,69,180]	No data	13,721 [66,450, 95] Carps: 698 [452, 25]	No data

Notes: SIS: Small Indigenous species; SPF: Specific Pathogen free;TSP: TripleSuperPhosphate; NPK: compound Nitrogen, Phosphorous and Potassium fertiliser

Fig. 1


Biodiversity land sharing, land sparing
Landscape v super-intensive systems; polycultures/monocultures
Animal welfare
Hatchery systems, intensive-extensive production systems
Reducing waste
• Production and processing 'wastes'
• Form of product marketed
Human nutrition-sustainable consumption
Quality and quality trade-offs
Rural economies
Urban-rural linkages
Broader sustainable development
Markets, employment through value chain; transferable skills
Increase production
Through higher yields..to safeguard the environment
SI as a goal-need for multiple approaches
Food security needs as much focus on environmental sustainability as productivity gains

Fig. 2


Market & public governance 'choice-editors':
National governments & regulating bodies
Certifiers (standards-setters, accreditation & auditing bodies)
Seafood buyers
Social and environmental NGO's
Transnational institutions (FAO, OIE, WTO, etc.)
Media
Consumers
Retail & food-service
Reprocessing
(value-addition)
Export logistics
Primary processing
Production
Inputs
seed, feed, technology
Legend
Value chain node
Horizontal linkages with local actors & communities
Value-chain linkages

Highlights

- **The concept of Sustainable Intensification is applied to the specific context of the global value chains linking production of farmed seafood in Asia and consumption in Europe**
- **Key sustainability issues are discussed that are currently not embraced by certifiers and other influential actors of farmed seafood governance**
- **Understanding demand, for the main and by-products, is critical to enhancing sustainable and more intensive aquaculture systems**

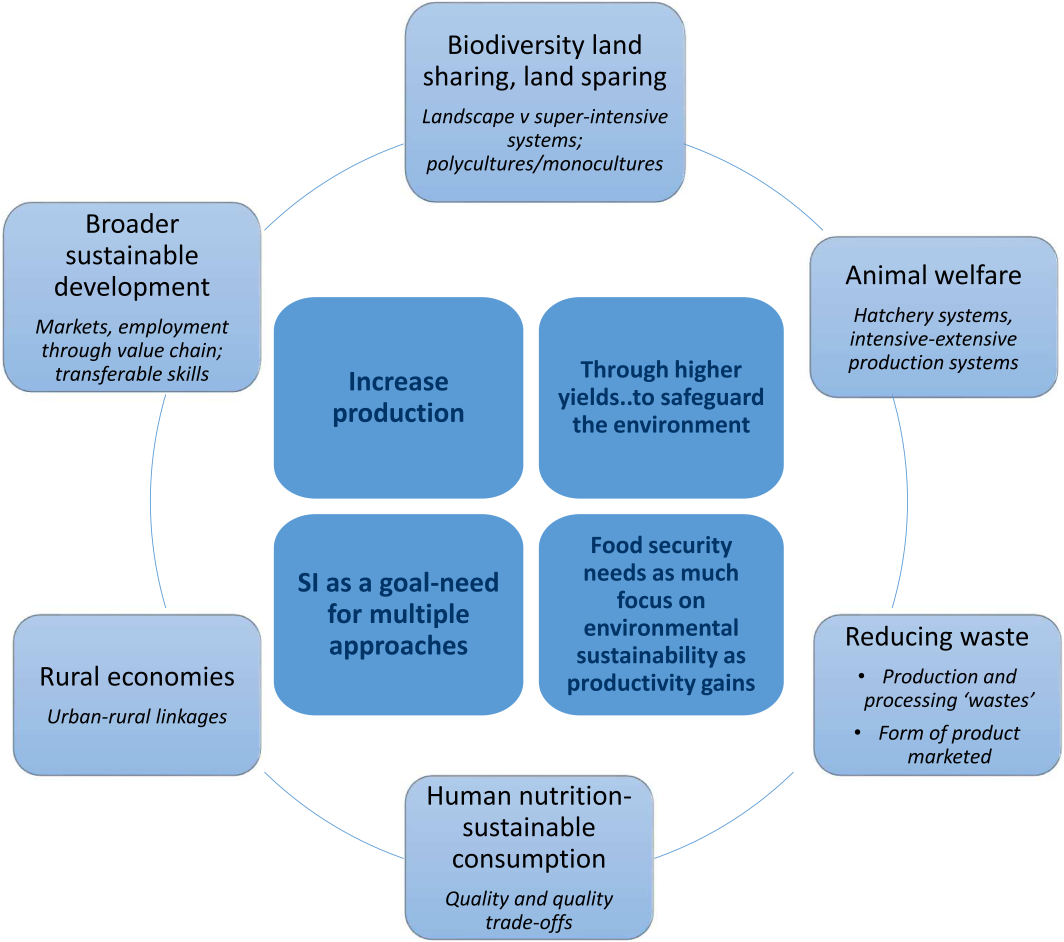

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Figure 1

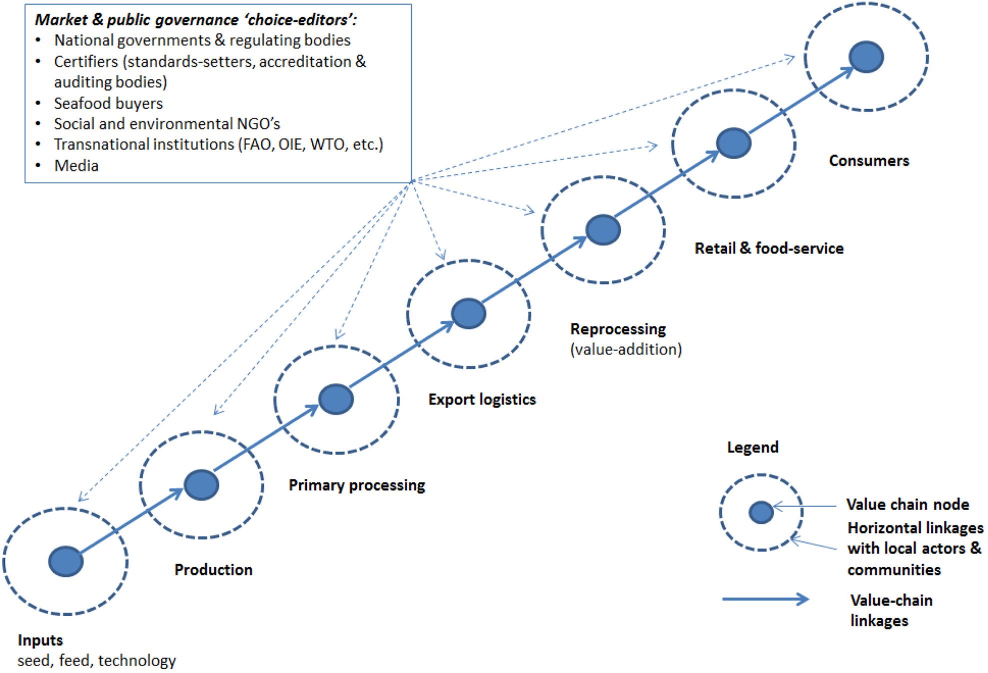
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Figure 2