Aquaculture 470 (2017) 129–148

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action

Olivier M. Joffre [a,b,*], Laurens Klerkx [a], Malcolm Dickson [c], Marc Verdegem [d]

[a] Knowledge, Technology and Innovation Group, Wageningen University, The Netherlands
[b] WorldFish, Phnom Penh, Cambodia
[c] WorldFish, Cairo, Egypt
[d] Aquaculture and Fisheries Group, Department of Animal Sciences, Wageningen University, The Netherlands

ARTICLE INFO

Article history:
Received 13 June 2016
Received in revised form 8 December 2016
Accepted 19 December 2016
Available online 21 December 2016

Keywords:
Innovation systems
Farming systems
Transfer of technology
Open innovation
New product development
Value chain
Inclusive innovation
Adoption
Systems innovation
Social-ecological systems

ABSTRACT

Aquaculture has experienced spectacular growth in the past decades, during which continuous innovation has played a significant role, but it faces increasing criticism regarding its ecological and social sustainability practices and the resulting challenges for future innovation processes. However, in the aquaculture literature, there is limited systematic knowledge of how innovation has been approached in terms of how the focus and the scope of aquaculture innovation processes are understood and managed. The objective of this paper is therefore to analyse the different approaches to innovation used in aquaculture development. We conducted a systematic review of the aquaculture literature, using an analytical lens derived from three main bodies of literature on approaches to conceptualize and manage innovation: *Technology-driven*, *Systemic*, and *Business and Managerial* approaches to innovation. One hundred publications were selected from the aquaculture literature covering the topic of aquaculture innovation. Analysis identified the *Transfer of Technology* approach as still the predominant approach to aquaculture innovation; and, even with the integration of elements of *Systemic* approaches, most studies remain focused on the farm level and are technology driven. Multi-dimensional studies, integrating technical, biophysical, political, and institutional dimensions of innovation in aquaculture were found, but studies analysing interactions between levels remain scarce, have a strong emphasis on the institutional dimension, and lack focus on the management of the innovation process. Studies with cross-fertilizations between different approaches to aquaculture innovation are limited but address specific research questions regarding the extent to which specific target groups are included in interventions and the need to incorporate diverse dimensions in analysing innovation processes. Our analysis suggests that aquaculture research and technology design that feeds into aquaculture innovation could benefit from innovation management approaches that integrate constant feedback from users, especially when specific groups are being targeted for better inclusiveness, and thus could better foster multi-directional interactions between multiple actors connected to aquaculture systems. This would help to elevate the analysis from just the farm and improve the integration of institutional, political, economic, and socio-cultural dimensions for better management of the innovation process. The study of aquaculture innovation needs to take into consideration the important role of private sector actors and make better use of systemic approaches to further elucidate the multi-dimensional and multi-level interplays in complex aquaculture systems. Ultimately, interdisciplinary research on aquaculture innovation could deliver significant insights supporting the development of a resilient and sustainable aquaculture sector.

Statement of relevance: Using an analytical lens derived from the literature on innovation approaches, this study systematically analyses approaches to innovation used in aquaculture development. We identify the main trends and existing gaps in aquaculture innovation research and then discuss the potential complementarities between different approaches to innovation in order to better understand and support innovation in the aquaculture sector.

1. Introduction

Aquaculture has become the most rapidly growing agricultural production system in the world over the last 40 years (FAO, 2012).

* Corresponding author at: P.O. Box 1135, Phnom Penh, Cambodia.
E-mail address: o.joffre@cgiar.org (O.M. Joffre).

http://dx.doi.org/10.1016/j.aquaculture.2016.12.020

Production of both fish and crustaceans has boomed, with an annual growth rate of 7.8% worldwide between 1990 and 2010 (Troell et al., 2014). This growth was enabled by the expansion of the area dedicated to aquaculture production and the intensification of aquaculture systems following important investments in the sector (see Appendix A for a brief overview of recent developments in the aquaculture sector).

Technological (e.g. breeding systems, feeds, vaccines) and non-technological (e.g. improved regulatory frameworks, organizational structures, market standards) innovations have enabled the growth of the aquaculture sector within a broad spectrum of production systems (Klinger and Naylor, 2012; Lebel et al., 2010). Mbabu and Hall (2012:16) define innovation as the 'the new use of existing or new ideas or the combination of ideas that have social or economic significance.' The generation, distribution, and use of new knowledge can refer to technological, social, organizational, and institutional changes (Leeuwis and van den Ban, 2004). Seminal work by Henderson and Clark (1990) suggests that innovation has four main levels of complexity based on the extent to which it involves new interfaces between (new) components and/or new components alone. They distinguish between i) incremental innovation based on pre-existing technological knowledge and organization of the components; ii) modular innovation that requires new technology but no change in the architecture of the components; iii) architectural innovation using known technology but requiring a change in the internal organization and interactions between components; and iv) radical innovation where the technology and organization change profoundly. Although this distinction was made several decades ago, it remains valid, and this classification continues to be widely used in innovation studies to distinguish different types of innovation (see e.g. Meynard, 2016; Xie et al., 2016). Innovation can mainly affect products, but, especially in the case of radical innovation, it may also lead to so-called system innovation in which whole productive sectors transform. System innovation encompasses several technological adaptations, as well as the development of products and processes and of broader institutional frameworks such as standards, regulations, and laws that govern value chains developed during the change process (Elzen and Wieczorek, 2005; Geels, 2002; Haasnoot et al., 2016). These different levels of complexity have also been acknowledged in aquaculture innovation (Bush and Marschke, 2014). Innovation may arise from different sources (public science, corporate R&D, local farmers' knowledge); involve different actors at different levels (farmers, feed companies, regulators, standard setters, and so forth); or operate within different political and economic contexts (Aerni, 2004; Alexander et al., 2015; Diana et al., 2013; Jespersen et al., 2014). These different levels of complexity influence the speed of innovation from the inception of the original idea to effective use of a new technology, product, or process. They also have implications for the number of actors contributing in some way or another to change processes by changing for example the way they work, produce, create policies and regulations, or consume.

Technological upgrading through incremental, modular, and architectural innovations in aquaculture is well documented in the scientific literature (e.g. Klinger and Naylor, 2012), but several authors have argued that radical and system innovation may be required to achieve the ecological and social sustainability of aquaculture (Bush and Marschke, 2014; Bush et al., 2015; Bustos, 2015; Diana et al., 2013; Sampson et al., 2015). After decades of spectacular growth, aquaculture is becoming more important than capture fisheries as a food production system (FAO, 2013). However, aquaculture feed uses significant amounts of aquatic (e.g. fish meal) and terrestrial (e.g. seed crops) resources (Naylor et al., 2000; Troell et al., 2014). This growth has had both social and environmental impacts, such as privatization of common resources (Hall, 2004), exclusion of producers from global aquaculture value chains (Islam, 2008), reduction of incomes and employment in the fishery sector (Stevenson and Irz, 2009), destruction and pollution of coastal and aquatic ecosystems (Hamilton, 2013; Primavera, 2006; Rico et al., 2012; Tilman et al., 2001), salinization of land and aquifers (Paez-Osuna, 2001), introduction of exotic species into ecosystems (De Silva et al., 2009; Naylor et al., 2005), transmission of disease and parasites to wild populations (Diana et al., 2013), and depletion of wild fish stocks to produce fish meal and fish oil used in aquaculture feed (Naylor et al., 2000; Klinger and Naylor, 2012; Deutsch et al., 2007).

In view of these challenges, new experimental aquaculture practices, inspired by systemic and business-oriented innovation management approaches, employ interventions such as innovation platforms or business incubators.[1] However, despite these new approaches to innovation management and although the scientific literature on aquaculture frequently touches on aspects of innovation in aquaculture, there is little systematic information on how innovation is conceptualized and described in the literature on aquaculture development and how this informs the management of aquaculture innovation. Analysing how innovation and its management have been approached in aquaculture will not only identify research gaps, but also inform future innovation management models to support aquaculture growth and contribute to global food system sustainability. Therefore, the objective of this paper is to build on an array of well-known and established approaches to innovation and to review how the aquaculture literature addresses innovation in terms of its conceptualization and management. This type of assessment looking at how innovation is conceptualized and analysed has been conducted in the agriculture and forestry sectors (Hansen et al., 2014; Klerkx et al., 2012; Pant and Hambly-Odame, 2009) but is still lacking for the aquaculture sector. We therefore analyse how aquaculture research has engaged with different innovation approaches, looking at two literature strands. The first strand analyses and describes innovation in aquaculture without having this as an explicit analytical focus (e.g. by presenting technical details of a new technology). The second concerns literature on innovation in aquaculture that explicitly analyses the conceptualization and management of innovation (e.g. by describing in detail the process by which technology was introduced and adopted, or how it has transformed a sector). By doing so, we want to identify gaps in the different approaches to innovation and provide a reflection framework to identify complementarities between the different approaches to inform future study and management of innovation in aquaculture.

To achieve this objective, we follow Adams et al.'s (2016) three-step review approach. In *Stage 1*, the analytical framework is constructed based on existing innovation theory. In *Stage 2*, the systematic review itself is carried out. In *Stage 3*, the results are discussed against the analytical framework to identify gaps in, and complementarities between, approaches to aquaculture innovation; and finally a reflection framework is proposed to inform future research on, and management of, innovation processes in aquaculture.

2. Stage 1: developing an analytical framework to review how innovation and its management are approached in aquaculture

In this review, we define an approach as a paradigm and a conceptualization that come with a set of methods and a specific way of analysis. We selected different approaches to how innovation is conceptualized and analysed, and connected to this how innovation management is organized, applied to the neighbouring fields of the natural resource management-based sectors of agriculture (Elzen et al., 2012; Foran et al., 2014; Klerkx et al., 2012; Pant and Hambly-Odame, 2009; Pant et al., 2015) and forestry (Hansen et al., 2014; Jarský, 2015; Kubeczko et al., 2006; Rametsteiner and Weiss, 2006; Stone et al., 2011). As the aquaculture industry is developing fast with a vibrant private sector, we also include in our selection approaches applied to industrial development and from

[1] See for example Maine aquaculture innovation centre (https://umaine.edu/cooperative-aquaculture/business-incubation/); WorldFish Incubator http://www.worldfishcenter.org/content/worldfish-incubator; New Jersey aquaculture innovation centre (http://aic.rutgers.edu/).

business management (Chesbrough, 2003; Montagna, 2011; Ulrich and Eppinger, 2004) in order to cast the net wide and capture a broad range of approaches to innovation that are potentially also relevant in the aquaculture sector.

It is beyond the scope of this paper to provide an exhaustive in-depth description of the different conceptualizations of innovation and related approaches to innovation management; hence we focus on the core elements of the different approaches (see Table 1). Our analytical

Table 1
Overview of approaches and theory to analyse innovation processes.

Approach	Technology-driven approaches		System approaches				Managerial and Business approaches	
Strand within approach	Transfer of Technology (ToT)	Farming Systems (FS) Thinking	Innovation Systems (IS)	Social-Ecological Systems (SES)	Systems Innovation (SI)	Value Chain (VC) Systems	New Product Development (NPD)	Open Innovation (OI)
Main goal of innovation as defined in approach	Transfer, diffusion, and adoption of technology	Develop innovation adapted to local context and constraints	Enhance capacity to respond to change and orchestrate stakeholders	Transformation of systems towards ecological sustainability and resilience	Transition towards a new more sustainable system comprising production system's value chain, regulatory environment, and consumption system	Value chain supporting equitable and sustainable sectors	New product responding to user requirements	Source knowledge from outside a firm's boundaries
Main scope of analysis	Productivity increase	Identify constraints to innovation within specific context	Analyse how to organize change	Dynamic analysis of non-linear and uncertain changes in coupled social and ecological systems	Understanding how actors influence change through power struggles, co-evolution between technologies and social structures	Analysing value chain regulation and power relationships	Feedback from users and other actors to design ideal products	Understanding knowledge sourcing in R&D process
Analytical focus point	Technology packages	Locally adapted knowledge and technology	Analyse how support structures for innovation (e.g. research) interact with stakeholders in production system, value chain, and policy system	Interactions between human and ecological systems across different geographical scales	Interactions between diverse actors at different levels in production system's value chain, regulatory environment and consumption system	Structure, organization, and coordination of the value chain	Joint design process of technologies and their context – whole systems design	Sources of knowledge and collaborative approach to achieve collaborative innovation
Geographical scale	Local	Local	Local to national and global	Local to global	Local to national and global	Local to global	Local	Local to national
Domains considered	Production system	Farming system	Policy system and value chain	Ecological and social systems	Policy system and value chain	Policy system and value chain	Production system	Production system
Role of institutions in the analysis	External drivers of adoption	External conditioner of adoption	Institutional and political dimensions and their interactions with other dimensions under consideration	Ecological aspects are dominant Limited attention to political context	Political dimensions of innovation and power struggles are included	Focus on governance and institutional framework that regulates interactions in value chain	Integrates regulatory framework in analysis to identify point to improve to make product fit	Understands institutional context and regulatory framework to access knowledge
Regions of application (developed/developing country)	Both	Both	Both	Both	Both	Both	Both	Developed
Flow of interactions to create, improve, or scale innovations	Top-down, initiated and pushed by research Linear, no feedback from end-users	Top down, initiated by research but participatory in nature	Multi-directional, can be initiated and driven by research, companies, farmers	Multi-directional Initiated by companies, farmers, research	Multi-directional and feedback interactions between levels Niche actors generally initiate the change	Multi-directional, change initiated by consumers, research, private sector	Multi-directional, iterative, and joint design production between actors Initiated by research or companies	Multi-directional Initiated by companies, transversal information flow across firms and other actors
Desired outcomes	Gain in yield, income, and food provision measured at farm level	Efficiency gain, productivity, economic and environmental outcomes (related to livelihood portfolio)	Increased capacity to innovate and learn	Identifies economic and ecological thresholds and (non-linear) linkages between subsystems	Sustainable new system	Changes in regulatory systems, institutional framework, and more equal power relationship between actors	New technology design fitted to user requirements	Creates better product and new business opportunities (e.g. agri-electronics)

Note: Approaches in this table are not mutually exclusive, and elements of a given approach can sometimes also be found in other approaches.

categories include the analytical focus points of the different approaches, the geographical scale of the analysis (local, regional, national, or global), the domains considered (production system, farming system, value chain, policy and regulatory system, social and ecological system), and the flow of interactions between actors that create, improve, and scale innovation (top-down, bottom-up, linear, multi-directional). We detail the role of institutions, including the normative and regulatory frameworks that guide behaviour within the innovation process, as well as the contribution of research to elements of the innovation or to innovation management. By using this analytical framework, we aim to identify the main innovation concepts and to analyse how different concepts are applied in aquaculture research. Existing gaps or complementarities between the conceptual approaches are identified, and directions for future research suggested.

2.1. Technology-driven approaches

Under technology-driven approaches, we distinguish *Transfer of Technology* (ToT) and *Farming Systems* (FS) *Thinking* (see Fig. 1 for an overview).

ToT, sometimes called the linear diffusion and adoption model (Leeuwis and van den Ban, 2004), is a technology-oriented approach driven mainly by mono-disciplinary research. It characterizes innovation as new technologies that are pushed from research, transferred by extension or advisory services, and adopted by users (Jarrett, 1985; Rogers, 1995). This approach looks mainly at determinants of adoption, which may be connected to the characteristics of both the adopter and the technology (Pannell et al., 2006). Context (e.g. policies, supply chain characteristics) is mainly seen as a conditioner of adoption, but it is only involved to a limited degree. The process from diffusion to adoption is considered to be linear, with limited active feedback from end-users during the innovation process (passive feedback may exist in the form of adoption or rejection of new technologies). Although diffusion and adoption thinking effectively illustrates the spread of mainly incremental innovations, it is a limited framework to understand system innovation where social and institutional dimensions and cross-scale interactions are central to the change process (Leeuwis and van den Ban, 2004).

FS Thinking arose in agriculture in response to criticism of the original ToT approach as being too focused on 'one-size-fits-all' technological solutions (Biggs, 1995). It contextualized technology through participatory research (Klerkx et al., 2012). Although it also emphasized continuous adaptation of technologies, it retained a rather technological and science-centred focus, concentrating mainly on innovation at farm level.

2.2. System approaches

There are four different *System approaches* (see Fig. 1 for an overview):

- Innovation Systems
- Systems Innovation
- Social-Ecological Systems
- Value Chain Systems.

2.2.1. Innovation Systems (IS)

The first type of system approach is the *Innovation Systems* (IS) approach, which arose out of innovation system theory used in industrial sectors (Edquist, 1997; Lundvall, 1992; Nelson and Rosenberg, 1993). An IS is defined as 'a network of organisations, enterprises and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect the way different agents interact, share, access, exchange and use knowledge' (Hall et al., 2006:vi–vii). IS emphasizes interactive learning between system components (e.g. farmers, traders, researchers, extension, policymakers), in order to enhance the capacity of the system to respond to change. From an IS perspective, the main driver of innovation is not exclusively research, because the role of research is broader than technology creation if the role of designers, facilitators, and policy influencers in innovation is taken into account (Schut et al., 2014). The IS approach can have different boundaries: national, based on a specific geographical area (Lundvall, 1992); sectoral, based on products or services (Malerba, 2002); or technological when the focus is on a specific technology that may be applied across different sectors (Carlsson, 1995). IS has become more prominent recently in the fields of forestry (Hansen et al., 2014; Jarský, 2015; Kubeczko et al., 2006; Nybakk and Hansen, 2008; Nybakk et al., 2011; Rametsteiner and Weiss, 2006; Stone et al., 2011) and agriculture (Klerkx et al., 2012; Pant and Hambly-Odame, 2009). Linked to this approach, and emphasizing the global dimensions of innovation systems, *Inclusive Innovation* (II) specifically emphasizes analysing the role of the poor within the process and outputs of innovation (Heeks et al., 2014) as part of a broader process of development that involves all potential stakeholders (inclusive development) (Gupta et al., 2015). The main scope of the analysis is to better understand the needs of the poor in order to inform innovation management approaches that enable the creation of innovations that are much better tailored to their needs. II shares the scope and core elements of IS but aims to understand

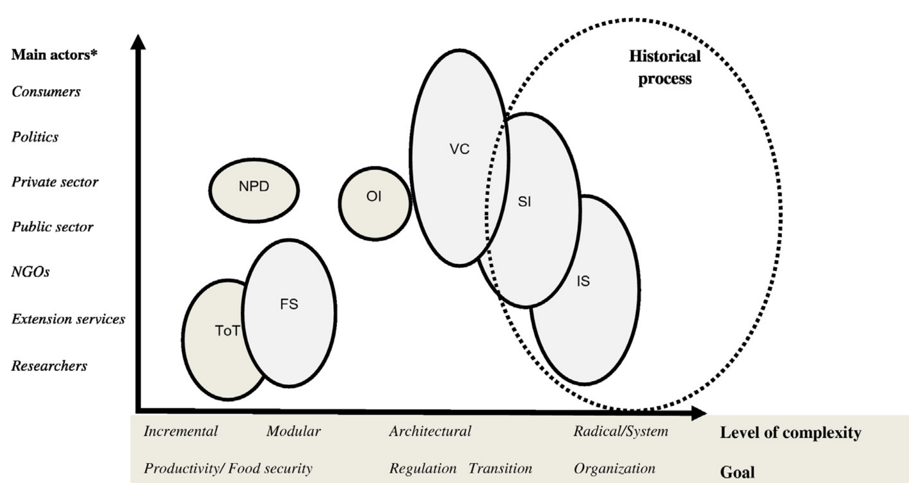

Fig. 1. Level of complexity, goal of innovation, and main actors (besides farmers) in the different approaches to aquaculture innovation. Note: *Main actors besides farmers. ToT: Transfer of Technology; FS: Farming Systems; IS: Innovation Systems; SI: Systems Innovation; VC: Value Chain Systems; NPD: New Product Development; OI: Open Innovation; the dashed oval represents approaches that draw their analysis within historical process, outside of the oval, studies are snapshots (contemporary).

institutional contexts and power relations between stakeholders as well as foster the inclusion of the poor.

2.2.2. Systems Innovation (SI)

The second type of system approach, *Systems Innovation* (SI), examines pathways of transformative change through system innovation (Geels, 2002; Grin et al., 2010; Rotmans et al., 2001). Similar to IS and II approaches, SI looks at the multiple interactions between diverse actors to produce innovation. Whereas the two former approaches focus more on the organization of these processes, analysis in SI aims to understand the dynamics of, and processes behind, change. SI applies a multi-level perspective (MLP). Three MLP levels are distinguished in SI processes: i) the niche is the space in which novel technologies and practices develop; ii) the incumbent socio-technical regime level indicates the current status quo of a sector or an industry in terms of elements such as dominant technologies and practices; iii) the markets, policy frameworks, and the broader landscape development level explores environmental, demographic, and political trends and crises that influence and induce change in sectors. An understanding is developed of how niche actors gradually change an incumbent regime by fostering multiple technological, social, organizational, and institutional innovations. Niche actors create momentum for change by processes such as the perfection of technology, lobbying those who establish rules and regulations, gathering resources such as finance, and envisioning how society and production systems should be shaped (Elzen et al., 2012). The innovation process is thus analysed as a co-evolutionary process between society and technology, which mutually influence each other and whose political dimensions of innovation and power struggles between niches and regimes are included in the analysis. Related innovation management approaches have been developed to foster learning in niches, such as strategic niche management and transition management (Loorbach and Rotmans, 2010; Schot and Geels, 2008; Smith and Raven, 2012). This approach, which initially sought to understand industrial transformation, has moved to fields like energy and mobility and has also been applied in agriculture (Elzen et al., 2012; Ingram, 2015; Roep et al., 2003) and forestry (Åkerman et al., 2010).

2.2.3. Social-Ecological Systems (SES)

The third system approach, *Social-Ecological Systems* (SES), is rooted in ecology and ecosystem management (Berkes and Folke, 1998; Holling, 1978). In this approach, the concept of resilience is central to understanding the dynamic interactions between coupled human and environmental systems. This concept acknowledges that systems have the ability to cope with disturbances and keep their functions and structure; systems can self-(re)organize and have the capacity to learn and adapt. However, they can also be pushed beyond thresholds, whereby rapid decline is induced. This approach offers a framework to understand cross-scale interactions of the ecological and social dimensions of natural resource management in sectors such as agriculture and forestry (Foran et al., 2014; Sinclair et al., 2014). SES analyses how socio-economic and biophysical driving forces interact to influence system change and induce transformations in systems towards ecological sustainability and resilience (Olsson et al., 2014).

2.2.4. Value Chain (VC) Systems

The fourth type of system approach, *Value Chain* (VC) *Systems*, is derived from the concept of a value chain and defined as: 'the full range of activities, including coordination, that are required to bring a specific product from its conception to its end use and beyond' (Gibbon and Ponte, 2005:77). This body of literature, widely applied in agriculture (Ayele et al., 2012; Devaux et al., 2009; Trienekens, 2011), focuses on institutional frameworks and value chain governance, shaped by the actors present at regional, national, and local level (Gereffi et al., 2005; Gibbon et al., 2008). The analysis distinguishes between internal actors (e.g. companies) and external actors (e.g. NGOs and certification bodies) influencing the value chain (Gibbon and Ponte, 2005; Nadvi, 2008). It relies mostly on governance mechanisms and examination of institutional frameworks (domestic and international regulations, market rules and mechanisms, and standards) that influence interactions and transactions in value chains. This approach draws attention to ways in which relationships are structured by power differences between actors (Gereffi et al., 2005), and how these in turn influence innovation in terms of who initiates and orchestrates innovation within the chain and who benefits from it (Pietrobelli and Rabellotti, 2009). VC systems approaches are increasingly linked to II approaches through inclusive value chain development with the aim of better involving all actors in the chain (especially smallholders) and achieving more equitable distribution of gains (Ros-Toonen et al., 2015).

2.3. Business and Managerial approaches

The third and last body of literature comes from business and managerial fields. Since the 1980s, an increasing body of literature has been documenting research on product development, focusing on different domains, from marketing to technology management and team integration (Page and Schirr, 2008).

2.3.1. New Product Development (NPD)

The first type of business and managerial approach, *New Product Development* (NPD), refers to processes through which new products are conceived, specified, developed, tested, and brought to market, and where users are consulted during the process (Montagna, 2011; Ulrich and Eppinger, 2004). This theory is rooted in industrial sectors, where design is given particular importance in order to create products well-tailored to users' needs. However, it has also found its way into agricultural systems design (Cerf et al., 2012; Groot Koerkamp and Bos, 2008; Sumberg and Reece, 2004; Sumberg et al., 2013). The process can be summarized as the transformation of a market opportunity into a 'ready to sell' product. Feedback loops from users and stakeholders involved in a joint development and design process are essential to the process, and the interactions between actors are multi-directional. The technical dimension predominates, and the level of analysis is focused on a concrete technological product, but the analysis integrates broader factors of the system in which the technology or the product are to be embedded. To ensure that the technology or the product fits within the system, it is necessary to identify areas that need to be adapted (e.g. regulatory frameworks).

2.3.2. Open Innovation (OI)

The second type of business and managerial approach, *Open Innovation* (OI), is defined as the efforts deployed by a firm to search for knowledge to innovate beyond their organizational boundaries (Chesbrough, 2003). It implies, for example, employing individuals that cross company boundaries, using technology licensing or new organizational liaisons, or bringing in external researchers and knowledge through partnerships aimed at solving specific issues. OI analysis includes research on interactions and collaborations between different sources of knowledge and technology within and outside firms, and how this is enabled or constrained (Agogué et al., 2013; Fichter, 2009; Katzy et al., 2013; Markus Perkmann, 2007). Examples of OI include private companies collaborating with universities to develop technologies and business models in precision agriculture (Grieve et al., 2009; Malik et al., 2011) but also in plant genetic resources in the agricultural sector (Borgen and Aarset, 2016; Oguamanam, 2013). Similar to the IS approach, OI is about creating opportunities to foster collaborative approaches to innovation, but more from a business than from a policy perspective.

3. Stage 2: systematic review of innovation in aquaculture

3.1. Method

We based our assessment on review methodology (Arksey and O'Malley, 2005; Levac et al., 2010) and a recent scoping review of fisheries and aquaculture (Béné et al., 2016). We built a three-step approach, including i) a systematic review and selection process of documents; ii) data extraction; iii) analysis of the results through the lens of the innovation approach outlined in Section 2.

3.1.1. Selection process

We used Scopus, and Aquaculture Science and Fisheries Abstract (ASFA) databases to search for academic research. The search included reviews, conference papers, book chapters, articles published in academic journals, reports, working papers, and studies published by institutions and governments. We limited the search terms to aquaculture production[2] in titles, abstracts, and keywords. We further limited the selected documents to *Technology-driven approaches*,[3] *System approaches*,[4] and *Business and Managerial approaches* to innovation.[5] In addition to the search, reference lists of pertinent articles were screened for supplementary publications and added to the selection process (Levac et al., 2010). Documents that belonged to several research sets were counted only in a single category of approaches to agricultural innovation.

We limited our search using the following inclusion/exclusion criteria: only documents published in English between 1960 and 2016 were selected; non-academic documents such as news articles and documents with insufficient details on methods were rejected; the quality of non-peer-reviewed documents was assessed to determine whether to include them; we selected only one reference among multiple documents reviewing the same innovation process based on the same dataset.

The document's degree of relevance was the final selection criterion. We screened titles, abstracts, and conclusions, and considered documents relevant if they analysed and/or described the innovation process in the aquaculture sector. These included studies explaining adoption of technologies to review papers analysing innovation at sector level. Studies covering only on-station trials and laboratory experiments, as well as studies on innovation in the processing of aquaculture products, were excluded.

3.1.2. Data extraction and analysis of papers

The selected studies were screened and categorized for: year of publication, title source, source of the data (primary, secondary data, and review), type of innovation, geographical area, habitat (freshwater, brackish water, marine), and species. We analysed the papers on innovation approaches using codes derived from the theoretical framework, which include for instance the boundaries of the innovation process (technological, sector, or national), the level of complexity of the innovation (incremental, modular, architectural, or radical/system innovation), the main scope of the analysis (productivity, food security, organizing innovation, analysing transition, sector regulation, access to knowledge), the geographical scale of the analysis (local, regional, national, global), and the temporal scale of analysis (contemporary or historical). The role of institutional and political dimensions in the analysis (absent, external, embedded, or central) was also considered, as were the role of farmers (adopter, expert, experimenter, partner, entrepreneur-producer), the flow of interactions (top-down, bottom-up, multi-directional), and entities with whom the farmers interact (researcher, NGO, extension services and government agencies, other value chain actors). We included the research methods (reviews, quantitative and/or qualitative surveys, consultation, experimental trials) and the type of innovation outcomes (productivity, food security, income, institutional and policy change, value chain organization and regulation) and how they are reported (type of indicators used, e.g. quantitative, qualitative). Each study was screened for its main and secondary theoretical framework to identify cross-fertilization between approaches to address specific research questions.

3.1.3. Analysis from approaches to innovation perspectives

The results of the individual selection are grouped and analysed by the three main bodies of literature relevant to agricultural innovation. Within each body, documents can be re-grouped into clusters with similar scope. For each group of documents, we first presented the diversity of innovation in the selected documents and their representativeness within each group. The selected documents were analysed for their approaches to innovation using the selected parameters. We present in the following sections the main highlights of the analysis. For a detailed analysis per innovation approach, see Appendix B.

3.2. Selection results

The first search returned 62,074 and 66,326 documents in Scopus and ASFA, respectively. When combined with *Technology-driven approaches*-oriented search terms, the quest returned 891 documents in Scopus and 1,682 documents in ASFA. A combination of the first search and *System approaches*-oriented search terms returned 2,308 and 3,543 documents in Scopus and ASFA, respectively (Table 2). A combination of the first search term and *Business and Managerial approaches*-oriented search terms returned 148 Scopus and 159 ASFA documents. After document screening (title, abstract, conclusion), 55 documents were selected in the *Transfer of Technology* category, 25 in the *System approaches* category, and four in the *Business and Managerial approaches* category. By screening references in the selected documents and applying 'snowballing', six documents were added to the *Transfer of technology* category, eight to the *System approaches* category, and two to the *Business and Managerial approaches* category. This resulted in a total of 100 documents classified according to the main type of approach (Table 2; Appendix C): *Technology-driven approaches* (61 documents, 61%), *System approaches* (33 documents, 33%), and *Business and Managerial approaches* (six documents, 6%). *Inclusive Innovation* and *Social-Ecological Systems* were not found as primary type approaches in the selected papers.

Articles published in aquaculture journals focused largely on production and/or economic dimensions, whereas non-aquaculture journals included *Systems Innovation*, *Value Chain Systems*, and *Business and Managerial approaches*. Publications focused on *Transfer of Technology* and *Farming Systems* approaches are spread across the 1993 to 2016 period, whereas publications on *Innovation System* approaches are more prevalent after 2007, and *Value Chain Systems* publications are more frequent after 2010 (Fig. 2).

---

[2] (fish OR shrimp* OR shellfish OR oyster* OR crab* OR salmon* OR tilapia OR carp* OR catfish* OR trout* OR pangasius OR seaweed* OR mussel* OR scallop* OR seabass* OR sturgeon* OR catla OR barb OR mrigal OR rohu) AND (aquacultur* OR production).

[3] *Technology-driven approaches*: {techn* dissemination} OR {techn* design} OR {techn* diffusion} OR {techn* transfer} OR adoption OR extension OR education OR {techn*impact} OR {techn*uptake} OR {farming system innovation} OR {locally adapted}.

[4] *System approaches*: {participatory research} OR innovation OR {system innovation} OR {innovation system} OR {inclusive innovation} OR {socio-technical regime} OR landscape OR {change management} OR communication or {innovation platform} OR interdisciplinary OR {learning platform} OR {innovation networks} OR {system learning} OR multilevel OR {multi-level} OR {social-ecological system} OR transformation OR resilience OR {political ecology} OR {transition management} OR {strategic niche management} OR {grassroots innovation} OR {cluster innovation} OR {pro-poor innovation} OR {knowledge network} OR {organizational learning} OR partnership OR {innovation network}.

[5] *Business and Managerial approaches*: {feedback loop*} OR {product design} OR {product development} OR NPD OR {Organizational learning} OR {partnership} OR {new product development}.

Table 2
Aquaculture innovation publications categorized by the dominant approach to innovation.

Approach	Clusters	Publications	Main journals (%)
Technology-driven approaches (n = 61; 61%)	Transfer of Technology (ToT) (n = 40; 40%)	Agbamu and Orhorhoro, 2007; Ahmed et al., 2011; Ahmed and Flaherty, 2014; Alvial, 2010; Azim et al., 2004; Baticados et al., 2014; Browdy et al., 2012; Foster and Demaine, 2005; Gupta et al., 1998; Gurung et al., 2010; Haque et al., 2010; Haque et al., 2014; Harrison, 1996; Hasan, 2012; Karim et al., 2014; Karim et al., 2016; Kripa and Mohamed, 2008; Kumar and Quisumbing, 2010; Liao et al., 2002; Little et al., 1996; Miyata and Manatunge, 2004; Murshed-e-Jahan et al., 2008; Nandeesha et al., 2012; Ndah et al., 2011; Nhan et al., 2007; Ni et al., 2010; Nyaupane and Gillespie, 2011; Paul and Vogl, 2013; Pouomogne et al., 2010; Prasad et al., 2012; Rauniyar, 1998; Roos et al., 2007; Rowena, 2013; Sandvold and Tveterås, 2014; Srinath et al., 2000; Tain and Diana, 2007; Tango-Lowy and Robertson, 2002; Thompson et al., 2002; Thompson et al., 2006; Wetengere, 2011	Aquaculture (10%) Aquaculture Economics and Management (7%) Journal of the World Aquaculture Society (5%)
	Farming Systems (FS) (n = 21; 21%)	Barman and Little, 2006, 2011; Basiao et al., 2005; Bogne Sadeu et al., 2013; Brummett et al., 1996; Brummett et al., 2011; Brummett and Jamu, 2011; Dey et al., 2005; Dey et al., 2010; Fast and Menasveta, 2000; Haque et al., 2015; Haque et al., 2016; Islam et al., 2003; Joffre and Sheriff, 2011; Karim et al., 2011; Martinez et al., 2004; Murshed-e-Jahan and Pemsl, 2011; Myers and Durborow, 2011; Nandeesha, 2007; Pant et al., 2014; Peacock et al., 2013	Aquaculture (14%) Journal of Applied Aquaculture (10%)
System approaches (n = 33; 33%)	Innovation Systems (IS) (n = 13; 13%)	Aarset, 1999; Ahmed and Toufique, 2015; Asche et al., 1999; Asche et al., 2012; Aslesen, 2007; Belton and Little, 2008; Belton et al., 2009; Doloreux et al., 2009; Fløysand et al., 2010; Galappaththi and Berkes, 2014; Giap et al., 2010; Hargreaves, 2002; Theodorou et al., 2015	Aquaculture Economics and Management (15%)
	Systems Innovation (SI) (n = 10; 10%)	Barton and Fløysand, 2010; Belton et al., 2008; Belton et al., 2011; Hall, 2004; Lebel et al., 2002; Lebel et al., 2009; Lebel et al., 2010; Saguin, 2015; Theodorakopoulos et al., 2012; Vandergeest et al., 1999	Journal of Agrarian Change (20%)
	Value Chain Systems (VC) (n = 10; 10%)	Aerni, 2004; Alexander et al., 2015; Anh et al., 2016; Bremer et al., 2015; Bush and Belton, 2012; Dey et al., 2013; Ha and Bush, 2010; Jespersen et al., 2014; Rosendal et al., 2013, Tran et al., 2013	Food Policy (20%) Aquaculture (20%)
Business and Managerial approaches (n = 6; 6%)		Abella, 2006; Acosta and Gupta, 2010; Aslesen, 2004; Aslesen and Isaksen, 2007; Sankaran and Suchitra Mouly, 2006; Tenkorang et al., 2012	R and D Management (16%) Water International (16%) Swedish Society for Anthropology and Geography (16%)

Note: Percentages indicate the relative importance of each group and cluster of publications relative to the total number of publications (n = 100).

3.3. Technology-driven approaches

3.3.1. Transfer of Technology

Of the 40 documents in the ToT category, 28 investigate why farmers adopt particular technologies. The scope of the studies is pond or farm level, and only four documents link farm level to sector or national level (Table 3). Technological boundaries define the studies in most cases (n = 36), and most aim to improve the productivity and financial returns from aquaculture systems. Incremental innovation is the most frequent type of innovation analysed. Innovation is mostly seen as concerning only technology, analysing past technology developments, and exploring future outcomes of recent technological changes (Browdy et al., 2012; Nandeesha et al., 2012). Policy and institutional contexts are either largely absent or considered external drivers to the adoption process. Adoption of new technology is viewed as a linear process, from researchers to farmers through a unidirectional process, with a central role played by extension services to facilitate this transfer.

The studies envision the farmer's role as the adopter of technologies (Table 4) but usually stop short of describing his/her participation in the innovation process (e.g. Gupta et al., 1998; Kripa and Mohamed, 2008; Rauniyar, 1998; Wetengere, 2011) even when their consultation as experts or as experimenters in on-farm trials is mentioned. In these cases, the outcomes of farmers' participation are not analysed or critically reviewed; and only two studies (Tain and Diana, 2007; Thompson et al., 2006) compare the results of adoption of aquaculture innovation from different extension approaches. The outcomes from technology adoption are usually assessed using on-farm trials, looking at productivity and the financial results of technology adoption (Azim et al., 2004;

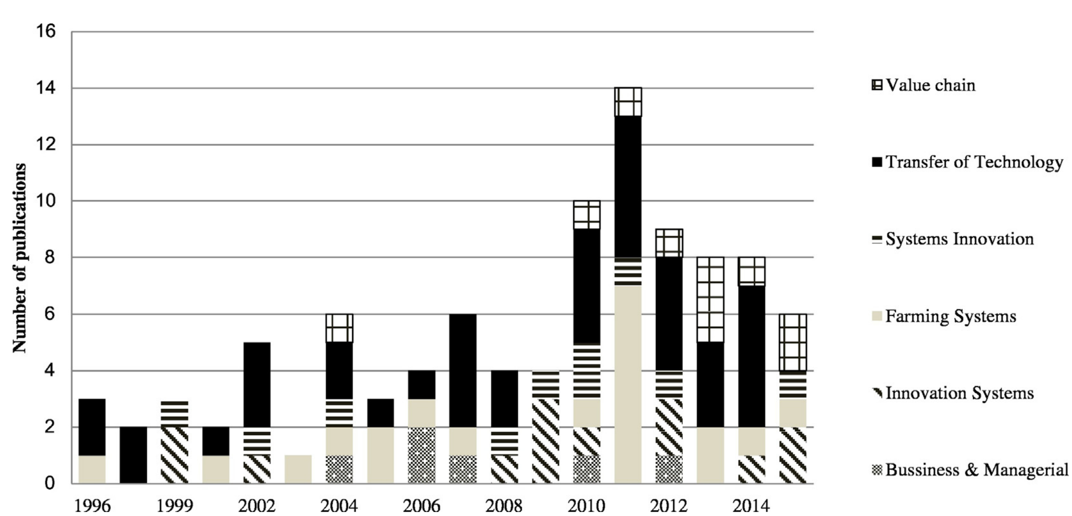

Fig. 2. Number of publications per approach between 1996 and 2016.

Table 3
Characteristics of approaches to innovation in aquaculture research.

n	Transfer of Technology (ToT) 40	Farming Systems Thinking (FS) 21	Innovation Systems (IS) 13	Systems Innovation (SI) 10	Value Chain & regulatory framework (VC) 10	Business and Managerial 6
Boundaries	Technological – 95% (national & sector)	Technological – 90% (sector)	Sector – 46% (national)	Sector – 70% (technological)	Sector – 50% (national)	Technological – 67% (national & sector)
Innovation levels	Incremental – 90% (modular, radical)	Incremental – 67% (modular)	System – 46% (incremental)	System – 80% (architectural)	Architectural – 70% Radical – 20%	Incremental – 67% (architectural)
Levels of analysis	Single at farm level – 90%	Single at farm level – 95%	Multiple – 54%	Multiple – 100%	Multiple – 70%	Single at farm level – 67%
Issue analysed/addressed	Productivity and/or poverty at farm level	Productivity, food security, and/or poverty at farm level	Organizing innovation	Analyses sector transition	Sector regulations and standards setting	Productivity, access to knowledge for sector
Relationship with policy institutional context	Absent or external – 98%	Absent or external – 90% (embedded)	Embedded or central – 85%	Central or embedded – 100%	Central or embedded – 100%	External or absent – 50% Embedded – 50%
Role of farmers	Adopter – 65% (expert, experimenters)	Partner – 62% (expert)	Entrepreneur/ producer —92%	Entrepreneur/ producer – 100%	Entrepreneur/ producer – 70% (partner)	Adopter – 67% (partner)
Interactions with stakeholders	Researchers, NGO, extension service – 48% (researcher; no interaction)	Researchers, NGO, extension service – 87%	Researchers, public sector, (private sector) – 100%	Multi-stakeholder interactions: public and private sector, extension (and politics) – 100%	Multi-stakeholder interactions: politics, public and private sector, NGOs, and consumers – 100%	50% – service provider and public sector (NGOs, researcher)
Research method and analysis	Socio-economic analysis at household level, livelihood framework, and regression analysis – 68% (on-farm trials)	Farm trial – 57% (surveys)	Review secondary data, policy & qualitative interviews	Review secondary data, policy & qualitative interviews	Review secondary data & surveys, consultation & qualitative interviews	Station trial, interviews, and consultation Review secondary data
Temporal scale	Contemporary – 80%	Contemporary – 72% (<10 years)	>10 years – 92% (contemporary)	>10 years – 80% (contemporary)	Contemporary – 60% (>10 years)	Contemporary – 50% >10 years – 50%
Geographical focus	South and Southeast Asia – 72% Africa – 12%	South and Southeast Asia – 71%; Africa – 23%	Europe/North America: 46% Southeast Asia: 23%	Southeast Asia: 80%	Southeast Asia: 60% Europe/North America: 30%	Southeast Asia, Europe, Africa, Oceania
Innovation outcome & indicators	Increase productivity at pond or household level – 48% Increase profit at pond or household level – 40% Increase food or nutrient intake per capita or household level – 13%	Increase yield or production at pond or farm level – 76% Increase income at household or pond level – 6% Increase in fish consumption per household or per capita – 5%	Increase in production at sector & national level – 23% Change in production cost – 23%	Increase in production at sector level – 20%; Change in operational cost (30%) and access to innovation by producers	Change in regulatory framework	Increase income and productivity at pond level – 33% New design Knowledge access

Note: The proportion of papers is indicated as a percentage for the main characteristic of the approach, and the second most frequent characteristic is shown in parentheses.

Prasad et al., 2012), or explicitly using sustainable livelihood frameworks or socio-economic household characteristics to analyse adoption and its impact on productivity, economic viability, and/or food security (see for example Paul and Vogl, 2013). However, comparison with control groups or baseline is not frequent, or the comparison is not based on robust methodology. This cluster is well represented within the selected sample, at 40% of the total selection. Its representation could, however, have been greater if we had considered experiments in controlled environments and experimental stations that also play a dominant role in aquaculture research.

3.3.2. Farming Systems

There are 21 documents relating to the *Farming Systems* approach, addressing productivity, food security, and poverty alleviation issues by improving existing, or developing new, technologies. The system boundaries are technological in most cases, and institutional dimensions are rarely included as external conditioners of adoption, such as exists in the case of collective action for aquaculture production (Dey et al., 2005; Joffre and Sheriff, 2011; Martinez et al., 2004). Interactions between researchers, extension services, and farmers, and the participation of farmers in the innovation process, are inherent parts of the studies (Bogne Sadeu et al., 2013; Brummett et al., 1996; Brummett et al., 2011; Dey et al., 2005; Islam et al., 2003; Murshed-e-Jahan and Pemsl, 2011) and acknowledged as having a predominant role in the design and adoption of innovation. However, details on feedback from, and on participation by, farmers in the design are limited and not analysed in these studies. The timescale of the studies is usually short, based on one production cycle or the length of a project, and innovation outcome indicators include socio-cultural acceptability, economic performance, food security, and, less frequently, environmental impact, but comparisons with existing practices are uncommon (see Murshed-e-Jahan and Pemsl, 2011 for an example). Although well represented, these studies are sometimes difficult to distinguish within the ToT type of studies, and the distinction between those two clusters can be seen as rather fluid, often with elements of FS added to ToT. Also, peer-reviewed journals that publish this type of research are technology oriented, focusing less on participatory process than on technology outputs. Consequently, the details about farmer participation and the description and analysis of participatory process are limited in these studies.

3.4. System approaches

System approaches publications are composed of 33 documents, of which five are reviews and 11 based on secondary data analysis. The remaining 17 documents are based on primary data observations, complemented sometimes with secondary data. The publications can be organized into three main clusters corresponding to different *System approaches* to innovation as outlined in Table 1.

3.4.1. Innovation Systems

Studies following this approach include 13 articles of which three are sector reviews (although not systematic reviews). The innovation system boundaries are at national or sectoral level, or national innovation system level (Aarset, 1999; Ahmed and Toufique, 2015; Asche et al., 1999; Asche et al., 2012; Aslesen, 2007; Belton et al., 2009), with limited inclusion of lower levels (e.g. farm, production system, pond) and interactions between levels. The system boundaries include institutional, technical, and socio-economic dimensions to explain transformation of the industry or to identify barriers to change and future challenges. Innovation is not analysed from purely technical or socio-economic perspectives, but the institutional context is embedded in the approach, as well as global drivers such as urbanization or international markets (e.g. Asche et al., 2012; Belton and Little, 2008; Theodorou et al., 2015). In these articles, the research reported analyses and provides solutions for organizing innovation.

The articles analysed indicate that different stakeholders participate in the innovation process but the interactions of farmers with researchers, extension services, or NGOs are not described, whereas interactions between the private and public sectors for innovation and diffusion of technical innovation are highlighted (e.g. Asche et al., 1999; Belton et al., 2009; Giap et al., 2010). The studies draw on historical processes, with a temporal scale encompassing often a period of time longer than 10 years and innovation outcomes estimated using national or regional statistics (e.g. Asche et al., 2012; Belton and Little, 2008). Productivity gains or production cost reductions cannot be credited to specific technical innovations, and food security outcomes are not assessed. This cluster has a strong focus on the salmon industry in Norway and other cases of aquaculture in the northern hemisphere. Developing countries, and especially Southeast Asia, are not well represented in this cluster.

3.4.2. Systems Innovation

The cluster of 10 articles looks at system innovations, at sectoral or national level, with a focus on Southeast Asian aquaculture development (Table 3). The analysis deals with the process of transformative change, with strong emphasis on political dimensions, institutional changes, and barriers to transformation. Authors use different concepts to look at systems innovation, such as transition theory (e.g. Lebel et al., 2002; Lebel et al., 2009; Lebel et al., 2010), political ecology (Barton and Fløysand, 2010; Hall, 2004; Vandergeest et al., 1999), or agrarian change theory (Belton et al., 2011), to present a dynamic perspective on aquaculture system innovation. Social dimensions of the transition and the outcomes on rural class structures, institutional and political changes, social justice, and power dynamics are emphasized in this cluster.

The studies acknowledge interactions and feedback between different levels and different dimensions – institutional, biophysical, technical, economic – but the analytical emphasis is on the role and influence of markets and institutions on the innovation process (e.g. Barton and Fløysand, 2010; Saguin, 2015), whereas the role of the technological subsector is less dominant. The analysis looks at successive transformation from niche (micro level) to regime (*meso* level), over a medium-term perspective (>10 years). Access to knowledge and the role of social-cultural factors in accessing knowledge are key to explaining the innovation process, and innovation does not depend only on extension services or researchers (Belton et al., 2011; Lebel et al., 2009). Other stakeholders such as the private sector, farmers' organizations, or farmers' social relationships are included in the analysis, and interactions between different actors are analysed to understand adoption of technologies (Theodorakopoulos et al., 2012) and/or transformation of the sector (Belton et al., 2011; Lebel et al., 2009; Lebel et al., 2010). National statistics are indicators of changes in the productivity and economic viability of the aquaculture sector in these publications, but food security outcomes from specific innovations are not assessed.

Even if this cluster is not well represented with regard to the overall sample (10%), it is interesting to note that this type of analysis is equally often represented as *Value Chain Systems* and is more dominant than *Business and Managerial approaches* in the literature. This representation can maybe be partially explained by our choice of source material (peer-reviewed articles only), where these types of academic studies are found. A majority of these studies are biased towards shrimp farming in Southeast Asia and aquaculture in South America (e.g. salmon in Chile), and none looks into northern hemisphere aquaculture transitions, although the analysis of such transitions could provide interesting insights and lessons.

3.4.3. Value Chain Systems

Studies within the *Value Chain System* (n = 10) look at architectural or radical innovation at sector or national level (Table 3) through two main types of research. The first type of research analyses current and past regulatory frameworks and value chains to provide recommendations in the context of future challenges (e.g. Aerni, 2004; Alexander et al., 2015). The second type of research reviews the development of quality standards in aquaculture value chains (e.g. Bush and Belton, 2012; Tran et al., 2013).

Institutions and policy are either embedded in, or central to, the analysis, and innovation is a process that can take place only with adequate institutional change. The level of analysis reflects the internationalization of aquaculture trade, with the development of standards (Bush and Belton, 2012) or the farming of transgenic fish (e.g. Aerni, 2004; Bremer et al., 2015). In these studies, the multi-dimensional aspect is less important, with less consideration of economic and biophysical factors, and the focus is on transformative change across different levels of the value chain (e.g. Bush and Belton, 2012; Ha and Bush, 2010). The studies are mostly grounded in contemporary analysis of value chains and regulatory frameworks (e.g. Alexander et al., 2015; Bremer et al., 2015), although analysis based on historical processes and medium-term changes were also found (e.g. Jespersen et al., 2014; Rosendal et al., 2013). The role of farmers is not necessarily described, as the boundary of the system is wider (sectoral or national), and the focus of these studies is generally not on farmers but rather on other actors in the value chain. They do not provide any primary data regarding outcomes on productivity, economic viability, or food security. This strong focus on certification of aquaculture commodities and value chain regulation does not include any in-depth case study of pro-poor value chain analysis for better inclusion of the poor. This absence could derive from our source material, which considered only peer-reviewed journal articles.

3.5. Business and Managerial approaches

This category includes only six documents: three peer-reviewed articles, two conference proceedings, and one report. The aim of the research in this cluster is to understand the flow of information that leads to innovation and the organization of public–private partnerships to create innovation. The boundaries of the studies vary from technological with incremental innovation at farm level to national with architectural innovation of the information and knowledge systems (Table 3). The two main approaches found within this cluster are: *Open Innovation* (OI) and *New Product Development* (NPD), the latter complemented with public–private partnership approaches.

The NPD concept is used to identify relationships between research and innovation in the production sector within a vertically integrated aquaculture firm (Sankaran and Suchitra Mouly, 2006) but with limited analysis of feedback loops within the NPD approach. Analysis of the public–private partnership process (Abella, 2006; Acosta and Gupta, 2010; Tenkorang et al., 2012) is limited, with no description or analysis of interactions between stakeholders, and institutional dimensions are not included in the analysis. Sources of knowledge for innovation in aquaculture and the behaviour of firms to acquire this knowledge are central to two articles (Aslesen, 2004; Aslesen and Isaksen, 2007) and refer to OI approaches. The studies analyse transversal transfer of knowledge in the aquaculture sector between firms, identifying the

Table 4
Strengths and weaknesses of the different approaches to aquaculture innovation.

	Transfer of Technology (ToT)	Farming Systems Thinking (FS)	Innovation Systems (IS)	Systems Innovation (SI)	Value Chain Systems (VC)	New Product Development (NPD)	Open Innovation (OI)
Strengths	Practical applicability with detailed technical solutions and adopters' characteristics Detailed analytical analysis of technology interventions at farm or pond level Analysis of technology outcomes and characteristics of adopters Quantitative evidence of innovation outcomes Farm-level focus related to project intervention	Practical applicability with participation of end-users to contextualize technical solutions and adopters' characteristics Detailed analytical analysis of technology interventions at farm or pond level integrating context and external drivers of adoption Quantitative evidence of innovation outcomes Farm-level focus relating to project intervention Considers different wealth groups in target population	Focuses on enablers of, and constraints to, innovation processes Applicability to guide research and policymakers with recommendation to better organize innovation system and identify constraints to innovation Holistic approach to understand innovation process with the integration of different dimensions Macro analysis to understand interactions across levels Considers institutional and political dimensions of change	Focuses on understanding innovation processes Applicability to guide research and policymakers by identifying political struggles and inequalities associated with innovation process Holistic approach to understand innovation process with the integration of different dimensions Macro analysis to understand interaction between levels. Considers institutional and political dimension of change Analysis of inequality and power relationships associated with innovation process and reflection on the distribution of benefits	Analysis of regulatory framework's change process and interactions between value chain's actors Applicability to guide research and policymakers with recommendations to regulate and organize the sector Detailed analysis of regulatory systems and implication along the value chain Qualitative analysis and evidence Macro analysis to understand interactions across levels Focus on institutional and political dimension of change Analysis of the inclusion/exclusion of small-scale producers Analyses changes in	Practical applicability with end-user participation to contextualize technical solutions Detailed analytical analysis of technology interventions at farm or pond level Farm- or firm-level focus	Focuses on understanding the complexity of innovation process with analysis of knowledge-sourcing by firms involved in innovation process Applicability to guide research and policymakers for better access to knowledge Detailed qualitative analysis of knowledge-sourcing by firms and role of regulatory framework based on qualitative evidence Farm- or firm-level focus for the analysis but integrates higher level elements in the analysis Considers institutional dimension of change

					benefits and redistribution of power along the value chain		
Weaknesses	Limited understanding of the complexity of the innovation process, with a focus on technology adoption Low applicability to guide research and policymakers, with no focus on broader enabling environment No holistic analysis of the innovation process Lack of qualitative evidence Ignores multi-level interactions Ignores institutional context Limited inclusiveness and ignores inequality between actors Absence of reflection on the distribution of benefits	Limited understanding of the complexity of innovation process, with a focus on participatory research Low applicability to guide research and policymakers, with no focus on broader enabling environment No holistic analysis of the innovation process Lack of qualitative evidence Ignores multi-level interactions Lack of institutional context, only considered as external drivers of innovation Limited inclusiveness	Limited practical applicability, with an analysis focusing on understanding change processes No or limited analysis of technical dimension and outcomes of intervention at household level Lack of detailed analytical analysis of the innovation process Lack of quantitative evidence of intervention outcomes Lack of detailed farm-level analysis Limited inclusiveness and ignores inequality and power relationship between actors Absence of reflection on the distribution of benefits	Limited practical applicability, with an analysis focusing on understanding change processes No or limited analysis of technical dimension and intervention outcomes at households level Lack of detailed analytical analysis of the innovation process Lack of quantitative evidence of impact of intervention Limited inclusiveness	Limited practical applicability, with an analysis focusing on regulation, organization, and policy No or limited analysis of technical dimension and intervention outcomes at households level Limited holistic approach to innovation, with lack of technical and ecological dimensions Lack of quantitative evidence of impact of intervention Lack of detailed farm-level analysis	Limited understanding of complexity of innovation process, with a focus on technical dimension and user needs Limited applicability to guide research and decision makers at sector level, with specific case studies No holistic analysis of the innovation process Lack of qualitative analysis of users' feedback Ignores multi-level interactions Ignores institutional context Absence of inclusiveness and ignores inequality between actors and the distribution of benefits	Limited practical applicability, with an analysis focusing on organization of knowledge access Limited holistic approach to innovation, with lack of technical and ecological dimensions Lack of quantitative evidence of impact Absence of inclusiveness and ignores inequality between actors and the distribution of benefits

use of internal and external knowledge to innovate within different types of aquaculture firms. Institutional and policy contexts are embedded within the analytical frameworks, and they combine elements of OI approaches (knowledge flow between actors external to the firm and the internal source of knowledge) and *System approaches*, integrating regulatory frameworks, different actors, and their interaction in the analysis.

The research methods in this cluster vary from on-farm research to production chain analysis, review of secondary data, and a series of interviews and consultations with different actors in the sector. Innovation outcomes are new products and designs (Abella, 2006; Acosta and Gupta, 2010; Sankaran and Suchitra Mouly, 2006; Tenkorang et al., 2012) or increased access to knowledge (Aslesen, 2004; Aslesen and Isaksen, 2007). The depth of analysis of public–private partnerships or product development is somehow shallow, and the number of publications is limited in comparison to the role that the private sector plays in technical and managerial innovation in the aquaculture sector – perhaps due to the absence of publications from the private sector. The results reflect a bias in the representation of aquaculture innovation research by the private sector in the scientific literature.

4. Stage 3: comparative analysis: gaps and complementarities between approaches

In this section, we first discuss the relevance of different approaches for specific geographic areas (Section 4.1). We then compare the strengths and weaknesses of the different approaches to innovation used in aquaculture development (Section 4.2), as described and analysed, or used and applied, by studies from the reviewed literature. The analysis leads to the identification of existing cross-fertilizations between approaches (Section 4.3) and to the definition of a reflection framework for both analysing and managing innovation in aquaculture combining different approaches (Section 4.4).

4.1. Geographical distribution of approaches

The review identifies some geographical patterns as regards application of the different approaches. Studies employing ToT and FS approaches focusing on productivity-improving innovation are dominant for developing countries located in South and Southeast Asia and Africa. In these studies, aquaculture innovation research remains linked to development project interventions at farm level and fails to integrate institutional context and policies. Brummett et al. (2008) already identified this research gap for African aquaculture and mentioned the need for policies to foster small and medium-scale aquaculture enterprises instead of the centrally planned and linear transfer of technology projects.

Although interventions to improve productivity are not reported in European or North American innovation research, they might still take place in such regions, but in the private sector, which would prevent their results from being published. In contrast, published research often focuses on only one component of the production system such as molecular, feed composition, or genetic research. The focus of published aquaculture innovation research in developed countries is oriented towards the regulation and organization of innovation within the sector, with many studies focused on value chain regulation for social equity and environmental concerns.

4.2. Different approaches for different purposes

Although *System approaches* account for 33% of the selected papers in the systematic review, our selection process might have influenced the result. The literature on *System approaches* included a larger number of search terms than the literature covering other approaches. In addition, we discarded several articles that analyse technology development only within controlled environments, thus rejecting most of the literature on technology design based on research station trials or laboratory experiments. Publications addressing ToT comprise more than 50% of the research published between 2010 and 2016.

Our analysis shows that each approach to aquaculture innovation, as used in the reviewed literature, is specific to the innovation level (i.e. incremental, architectural, system, or radical), the issue analysed, the type of interaction with different stakeholders, or the temporal scale (Table 3). However, it is problematic when there is a mismatch between the complexity of the issue to be addressed and the approaches chosen to understand or stimulate the specific innovation process (Section 4.2.1, 4.2.2, and 4.2.3). We compared systematically the strengths and weaknesses of the different approaches, taking into account: (i) the level of analysis (micro or macro level) and the analysis of multi-level interactions; (ii) the type of contribution to innovation research (practical applicability for practitioners or supporting the understanding of innovation process); (iii) the level of applicability for guiding researchers, practitioners, and decision makers; (iv) the institutional environment; and (v) the type of analysis (analytical, holistic). We also compared approaches with regard to the nature of analysis (qualitative or quantitative) (vi); evidence of outcomes and impact (vii); integration of inclusiveness (extent to which specific target groups are included) (viii); and presence of critical reflection on equity issues (ix) (Table 4).

In this analysis, we distinguish between the intended contribution of the research reported in the articles to aquaculture innovation by providing technological or non-technological novelties that can be deployed or implemented, and the intended contribution of the research to the understanding of the innovation process and transformation of the sector that supports the design of future innovation management interventions. The level of intended direct applicability as reported in the articles is considered high when it entails innovations that are ready to be deployed on the ground by practitioners, when it entails for example detailed and ready-to-implement proposals for re-organization of the sector, or new regulatory frameworks to be taken up by organizations and other stakeholders involved in the sector (although there may be a risk of non-adoption if these innovations are disconnected from, or not tailored to, the context – as argued in system approaches). We oppose that to studies with a lower intended level of applicability as reported in the articles when these generate broad recommendations that are either generic or necessitate additional analysis or study before being translated and deployed locally by local practitioners and stakeholders. The latter can include recommendations or critiques calling for further understanding of sector transformation or recommendations regarding changes in regulatory frameworks to benefit specific target groups, but without specific proposals on how to do this.

4.2.1. Strengths and weaknesses of Technology-driven approaches

The *Farming Systems* (FS) approach shares purposes and boundaries (on-farm technology development) similar to the *Transfer of Technology* (ToT) approach. The transition between the two clusters of publications is fluid, with common attributes found in both types of publications. Studies from both clusters focus on innovation at farm level. Their strengths lie in providing guidance for practitioners with concrete technology and practice proposals rather than understanding innovation processes and guiding re-organization at sector level. In contrast to *System approaches*, they both see the role of policy and institutions as external to their analysis. One strength of the FS approach compared to the ToT approach is the stronger acknowledgement of farmers whenever they are involved as *knowledge partners*. A weakness of both ToT and FS studies compared to *System approaches* is that they do not address system or radical innovations that require transformation of the sector, new regulatory frameworks, and/or institutional changes, or changes at levels higher than the farm, and do not respond to more transformative innovation challenges beyond technical factors or capture the negative social and environmental impact at landscape level. The innovation process is still perceived as mainly technological, assuming that only incremental innovation is required and that support systems, markets, policies, or regulatory frameworks do not influence the uptake of new technology. The practical applicability of the technological innovation and the guidance for the practitioner are high in technical guidance and testing at farm level. Because the institutional context of innovation is not addressed (Table 4), insight into key factors for innovation success are insufficiently developed, making the outcome of applying the same approach in a different adopter's setting unpredictable.

The FS studies' strengths lie in paying better attention to contextualization and adaptation to local needs than the ToT, with a higher level of interactions with the end-users and including in some cases other value chain stakeholders (e.g. Agbamu and Orhorhoro, 2007; Haque et al., 2010; Murshed-e-Jahan and Pemsl, 2011) and the mention of participatory approaches. However, documentation of interactions between actors, and specifically between researchers and users in the innovation process, is weak (e.g. Barman and Little, 2011; Brummett and Jamu, 2011), and studies following ToT or FS approaches remain top-down and led by researchers.

A weakness of ToT studies is the lack of contextualization and the failure to acknowledge adopters, as, for instance, when an intervention aims at poverty alleviation by relying on an aquaculture technology that is not accessible to the poor. In such instances, for the innovation to be successful, it is necessary to analyse the extent to which target groups are included in an intervention (inclusiveness) and the distribution of benefits and equity beyond technological benefits. The latter does not always take place, as found in some SI studies. In FS studies, the technological interventions analysed claim, in many cases, to target poverty alleviation. However, inclusive innovation that specifically addresses the development of technology with and for the poor is weak, found only in Pant et al. (2014) and Barman and Little (2006).

4.2.2. Strengths and weaknesses of System approaches to understand innovation processes

Studies classified as *Innovation Systems*, *Systems Innovation*, and *Value Chain Systems* differ in their purpose from studies of the *Technology-driven approaches* cluster: they generally aim at understanding innovation processes and identifying barriers to innovation by unravelling specific determinants of innovation (e.g. adopter characteristics, power relationships, institutional barriers). Compared to studies using FS or ToT approaches, they are more critical and evaluative than action oriented. Their strengths lie in drawing their analysis from historical processes to identify past and current barriers to innovation and past drivers of change of diverse national sectors (e.g. Asche et al., 2012; Fløysand et al., 2010; Lebel et al., 2010).

The practical applicability of IS approaches in guiding research and supporting policymaking remains rather abstract, as these focus at the system level (Table 4), with little direct applicability of the recommendations. *System approaches* studies' strength is their focus on understanding complex innovation dynamics, rather than looking at ways to facilitate these processes. Hence, in the selected publications, some key features of IS approaches, such as multi-stakeholder platforms to stimulate innovation, are absent. Another strength of these studies is that they address environmental issues (e.g. Ahmed and Toufique, 2015; Barton and Fløysand, 2010) and aim for sustainability rather than just increasing productivity. A common weakness of these studies is the lack of a farm-level analysis of the challenges to innovation (e.g. Asche et al., 2012; Theodorou et al., 2015) compared to *Technology-driven approaches*. Moreover, there is limited critical analysis of inclusiveness and reflection on equity issues.

Studies following an SI approach were deployed to analyse the rapid transformation of Southeast Asian aquaculture that led to political and social conflict over the use of natural resources. Information on power relationships, inclusiveness, and the degree to which different actors gain or lose during the innovation process is a strength of the analysis, as it elucidates the distribution of benefits and equity (Table 4). Compared to *Technology-driven approaches*, the main weaknesses of SI studies concern the lack of precision regarding the technological subsector

Table 5
Actual cross-fertilization between approaches to analyse aquaculture innovation.

Question addressed	Cross-fertilization	Reference
Understanding linkage between livelihood portfolio and adoption of innovation	ToT + FS	Haque et al., 2014; Nhan et al., 2007; Paul and Vogl, 2013; Pouomogne et al., 2010; Thompson et al., 2002
Innovation for the poor	(ToT, IS) + II	Ahmed and Flaherty, 2014; Barman and Little, 2006, 2011; Karim et al., 2011; Karim et al., 2016; Nandeesha, 2007; Pant et al., 2014;
Understanding source and flow of knowledge in innovation systems	(IS, ToT) + OI	Aslesen, 2004, 2007; Aslesen and Isaksen, 2007
Social and environmental outcomes of innovation	IS + SES	Peacock et al., 2013.
Understanding change in sector organization, with emphasis on political and institutional transformation	IS + SI	Barton and Fløysand, 2010
Transformative value chain analysis and understanding power relationship between actors	VC + TT + (IS, II)	Anh et al., 2016; Bush and Belton, 2012; Ha and Bush, 2010; Tran et al., 2013
Understanding how power relations determine access to, and flow of, knowledge	SI + OI	Belton and Little, 2008, 2011

Note: ToT: Transfer of Technology; IS: Innovation Systems; FS: Farming Systems; Inclusive Innovation: II; Open Innovation: OI; Value Chain Systems: VC; Systems Innovation: SI; Social-Ecological Systems: SES; Transition theory: TT.

(e.g. Hall, 2004; Vandergeest et al., 1999) and the limited applicability to guide innovation at farm level (e.g. Lebel et al., 2010). The analysis generally provides only recommendations to drive future changes and re-organize innovation systems, with limited practical applicability for interventions in terms of technologies or business models, but more applicability for guiding future research and informing policymakers.

The approaches used by VC studies generally aim to understand architectural innovation and to deliver insights to address societal and environmental concerns raised by consumers, especially those relating to the rapid change in Southeast Asian aquaculture sectors (Table 4). Their strengths lie in their multi-level focus, from the local to the international level (Table 3), and the importance of institutional and political dimensions. However, ecological and technical dimensions and subsystems are underemphasized, and thus these approaches lack insights at farm level. Compared to other *System approaches* and *Technology-driven approaches*, the studies integrate new types of stakeholders (consumers), widening the boundaries of the system and providing specific outcomes regarding the organization and regulation of the sector (e.g. Jespersen et al., 2014; Tran et al., 2013). The outcomes of the studies are aimed at supporting policymakers and guiding research at sector level, but have low practical applicability as they provide global recommendations that will requires additional research to design concrete new regulations or organizational arrangements (e.g. Ha and Bush, 2010; Rosendal et al., 2013). Also, conclusions can lack direct applicability for policymakers (e.g. Aerni, 2004).

4.2.3. Strengths and weaknesses of Business and Managerial approaches

Studies from the *Business and Managerial* cluster focus on the role of the private sector within the innovation process with an analysis of productivity and the degree of access to knowledge afforded by actors in the sector (Table 3). *New Product Development* studies aim to provide insight on how to innovate, with direct practical applicability for practitioners. In contrast, *Open Innovation* studies focus on understanding innovation processes and have a degree of applicability at sector level to inform future research and policymakers (Table 4).

NPD studies have technological boundaries involving incremental innovation at farm level. The approach used by the studies is detailed,

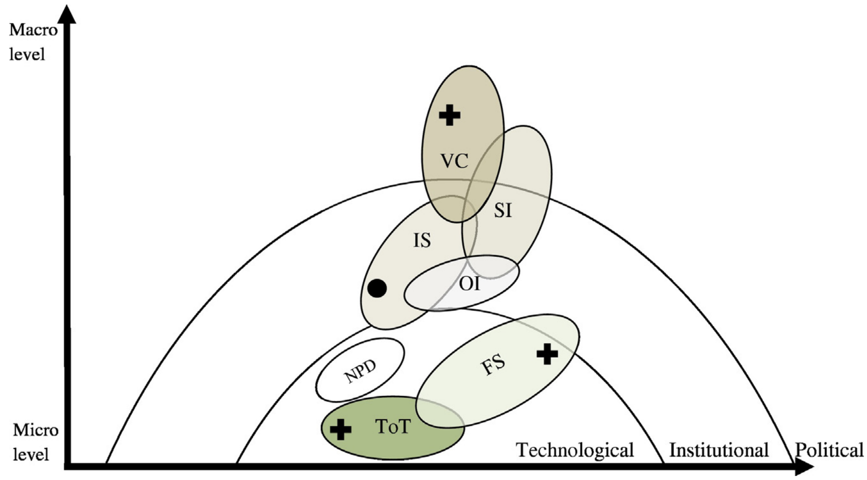

Fig. 3. Actual cross-fertilization between approaches and across different dimensions and levels. Note: ToT: Transfer of Technology; FS: Farming System; IS: Innovation Systems; SI: Systems Innovation; VC: Value Chain Systems; NPD: New Product Development; OI: Open Innovation; + represents Inclusive Innovation and ● represents Social-Ecological Systems.

but quantitative evidence is limited, and qualitative feedback from users is not found at all (Sankaran and Suchitra Mouly, 2006), limiting the interest in this bottom-up approach. In response to users' technical needs, the technology is contextualized, but the weaknesses of such studies lie in the lack of reflection on equity, a multi-level focus, and no account taken of institutional and ecological dimensions. In OI studies similar weaknesses are found. The studies concern architectural innovations, with a focus on transversal knowledge transfer from the outside to aquaculture firms, and analysis at farm level. Their practical applicability is low, with very generic recommendations to guide policymakers to organize the sector to facilitate access to knowledge (Aslesen and Isaksen, 2007). Implementing the recommendations requires additional studies to design the intervention and the re-organization of the sector.

Compared to other types of approaches, the number of OI and NPD studies in aquaculture innovation research is limited; this highlights a gap in aquaculture innovation research. Overall, firms, industries, and other private sector stakeholders are key actors in aquaculture innovation and contribute to sector growth but rarely appear in the aquaculture innovation literature. Lack of documentation from, or access to, either results of private sector-led research on product development or system-level research can explain the gap. It also indicates that documented research on aquaculture innovation is strongly influenced by public funding and does not necessarily cover successful private-sector innovation or innovation emerging from the aquaculture sector itself. This situation leads to over-representation of internationally funded small-scale aquaculture projects, as analysed by Belton and Little (2011).

4.3. Current cross-fertilization to benefit from complementarities between approaches

Our analysis examined how different approaches to innovation can be found in the aquaculture literature, and their strengths and weaknesses in addressing specific issues (e.g. productivity, poverty alleviation, sector organization, sector transition). We found that, in some of the reviewed articles, more than one approach or some elements of additional approaches were used. This can be defined as cross-fertilization

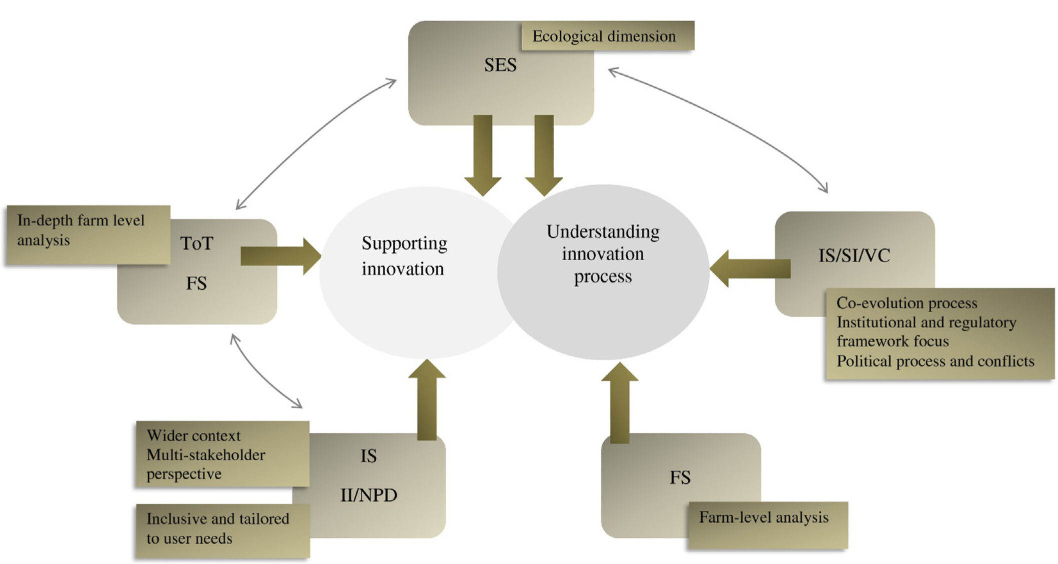

Fig. 4. A new framework to understand and manage innovation in aquaculture. Note: ToT: Transfer of Technology; IS: Innovation Systems; FS: Farming Systems; Inclusive Innovation: II; Value Chain Systems: VC; Systems Innovation: SI; Social-Ecological Systems: SES; NPD: New Product Development.

Table 6
Gaps and complementarities between approaches to aquaculture innovation.

Main approaches to	Main gaps	Complementary approach	Gap addressed by complementary approach
Understand innovation			
IS, SI, VC	Lack of in-depth analysis at producer level	FS	Adds technical dimension and farm-level perspective
IS	Political dimension of development lacking	SI	Adds political dimension to the analysis
IS, SI	Weak or no linkages between innovation and ecological systems	SES	Adds social-ecological linkage to the analysis
ToT, FS	Lack of institutional dimension and multi-level approach to better understand the wider context	IS	Frames innovation in wider context with multi-level approach and adds institutional and governance aspect during design phase (i.e. better anticipating the enabling context for technology embedding)
ToT, FS	No linkages between innovation and ecological systems	SES	Better assesses linkages between social and ecological dimension of new technology and possible ecological consequences
Support innovation			
ToT, FS	Absence of other stakeholders apart from farmers during intervention design	II, NPD, IS, SI	Multi-stakeholder platforms for action-driven innovation and multi-level perspective to stimulate joint technology development and anchoring of novelty in broader context Joint design approach with the integration of feedback from multiple stakeholders to better fit the product or technology to the context
IS, VC	Lack of producer-level analysis and inclusiveness	II, NPD, FS	Joint design approach and inclusion of specific target group Adds technical dimension and farm-level perspective

Note: ToT: Transfer of Technology; IS: Innovation Systems; FS: Farming Systems; Inclusive Innovation: II; Value Chain Systems: VC; Systems Innovation: SI; Social-Ecological System: SES; NPD: New Product Development.

between approaches that can be used either to enhance our understanding of innovation processes or to better manage innovation.

First, a complementarity between ToT and FS approaches is used in the literature to contextualize innovation and understand how the innovation can improve not only productivity but also food security and income at household level (Table 5; Fig. 3). Thompson et al. (2002) report how elements of FS approaches are used to better understand how a technological intervention can be tailored to fit the context for better outcomes and to integrate specific innovations within the portfolio of household activities. This type of synergy is common and found in several studies relating to ToT (Haque et al., 2014; Nhan et al., 2007; Paul and Vogl, 2013; Pouomogne et al., 2010), with to a certain extent an increasing degree of participation in research and consequently the transformation of farmers' role from adopters to experts and experimenters. Practical support for on-farm innovation, however, often remains limited to providing extension services employing a linear diffusion of technology approach, with a limited level and limited evidence of farmers' participation. Several studies following both ToT and FS include elements of II, looking at tailoring technologies to specific target groups. From II theory, only elements regarding exclusion/inclusion of specific groups are integrated in the research (e.g. Barman and Little, 2006; Pant et al., 2014). Studies also look at specific constraints experienced by the poor in adopting new technology (Karim et al., 2011) or the role of women in innovation (Nandeesha, 2007). However, although II looks at power relations and how they change overtime, this element is not integrated in the aforementioned studies.

Another, not explicitly mentioned, instance of cross-fertilization uses elements of *Social-Ecological System* theory with elements of *Innovation Systems* research (Peacock et al., 2013). The study includes a typical *Innovation Systems* approach-inspired multi-stakeholder platform as support to innovation to encourage new salmon farm management practices benefiting wild salmon populations. The study acknowledges links between institutional and ecological dimensions, but feedback loops, cross-scale interactions, and non-linearity of change are not integrated in the research. *Innovation Systems*- and *Open Innovation*-oriented papers share elements when the focus is on the flow of interaction between actors and source of knowledge for aquaculture firms (Aslesen, 2004, 2007; Aslesen and Isaksen, 2007). Another actual cross-fertilization is found in Barton and Fløysand (2010), where combined elements of *Innovation Systems* and *Systems Innovation* approaches with a strong focus on political struggle and institutional transformation were used to understand the changes in the organization of the Chilean aquaculture sector.

The reviewed papers highlighted additional instances of cross-fertilization between *Transition theory* and *Value Chain Systems* approaches. For example, framing their study within value chain approaches, Anh et al. (2011) explicitly point to the multi-level approach, looking at interlinked initiatives at the international, national, and community level. They add co-evolutionary processes and institutional dimensions of *Transition theory* to value chain analysis. Using elements of both approaches helps to better understand the enabling or constraining factors for establishing standard setting at different levels and the transformation of value chain organization and regulation. Belton and Little (2008, 2011) integrate *Open Innovation* elements by focusing on knowledge sources and link this to power relationships analysis to explain the transition of the catfish aquaculture sector in Vietnam. However, these studies do not provide concrete suggestions about how better to design practical support for innovation.

4.4. Towards a reflection framework to better understand and manage innovation in aquaculture

In Section 4.3, we identified existing complementarities between approaches to understand innovation in aquaculture and consequently to manage innovation in aquaculture. Following Bush and Marschke (2014), we argue that, in order to improve our understanding of the rapid change in aquaculture, researchers need to make a bridge between concepts and create complementary approaches to address complex problems. Therefore, we propose a reflection framework to benefit from the complementarities in the different approaches to the study and management of innovation in aquaculture. This reflection framework is composed of two main clusters of complementarities between approaches: a first cluster to better understand innovation processes and a second cluster that aims at supporting aquaculture intervention design (i.e. innovation management) (Fig. 4).

Current approaches used to understand and support aquaculture innovation display gaps regarding the absence of multi-level and multi-dimensional perspectives, a lack of consideration of the environmental dimension, the absence of an inclusive approach (and method), and a failure to include a multi-stakeholder approach to aquaculture innovation (Table 6). We identified different complementarities between approaches that will help to fill this gap to support aquaculture innovation.

The first cluster of complementarities contributes to better understanding (i.e. conceptualizing, analysing) innovation processes in aquaculture in a comprehensive way (Fig. 4). We found that *System approaches* lack a focus at farm level, and neither *Technology-driven approaches* (ToT and FS) nor *System approaches* integrate enough of the environmental dimension (Table 6). IS approaches lack a political dimension to understand the wider context and power relations, and ToT and FS approaches do not consider the wider context in order to facilitate uptake of technological innovation. This first cluster of complementarities encompasses different *System approaches* that complement and strengthen one another to better understand innovation processes, but also deepen the understanding of *Technology-driven approaches* by using elements of *System approaches*.

Various *System approaches* are deployed in the reviewed studies to understand the innovation process but sometimes without acknowledging the technical dimensions and overlooking the farm level. We have already identified complementarities between VC approaches and *Transition theory* or IS and II to better analyse the transformative change within value chains and understand power relationships between actors. However, within *System approaches*, the inclusion of elements of FS approaches with a focus on the technical dimensions of innovation could provide better insight into transformative change at farm level and, perhaps, also provide quantitative evidence of change. Meanwhile, combining multi-disciplinary research with in-depth analysis and later integrating the two will require additional effort. Lack of political dimensions in IS studies could be addressed by complementing this approach with elements of SI (e.g. elements of political ecology or agrarian change theory for example – see also Foran et al., 2014) and provide a better understanding of the wider context and power relations during the innovation process.

Meanwhile, aquaculture development is often criticized for its environmental impact. Studies using ToT and FS approaches lack the environmental dimension and linkages between farm-level aquaculture innovation and the local environment. Framing these technical studies at farm level within *Social-Ecological Systems* (SES) theory could help to identify linkages between farming and wider ecological systems and, in turn, provide recommendations and develop resilient and sustainable technologies. Environmental factors are often addressed from a political point of view through SI approaches. Complementing SES theory with IS or SI approaches could provide better insight into understanding innovation process and interactions between innovation and ecological systems at a higher scale than the farm and anticipate negative trade-offs relating to aquaculture innovation.

Finally, FS and ToT approaches conceptualize adoption of new technologies in a similar fashion. Both presume a central role for the government and extension services but fail to acknowledge multi-stakeholder participation to support the design and anchoring (i.e. embedding within wider infrastructures, social and institutional structures) of technological innovations in aquaculture. The design of technological innovation can integrate elements of multi-level perspectives to stimulate innovation (Elzen and Bos, 2016), by looking at how technology needs to co-evolve with broader institutional and social changes.

The second identified cluster of complementarities contributes to better managing innovation. ToT and FS studies that lack institutional dimensions and multi-level approaches, and do not address system and architectural innovation, could gain from including elements of IS approaches, such as innovation platforms, in the early steps of technology development (e.g. during the diagnostic phase). Multi-stakeholder platforms used as part of an *Agriculture Innovation System* approach can also support multi-directional exchange of information between researchers, farmers, and other stakeholders (private sector, policymakers, and extension services) and thus contribute to closing the knowledge exchange gap between stakeholders and target beneficiaries of the technological innovation (Kilelu et al., 2013; Klerkx et al., 2013; Swaans et al., 2014). Using such elements of the IS approach will help to integrate the role of private sector actors, as, despite being the drivers of aquaculture development, they are often not included in innovation research on aquaculture.

Complementarities between II and FS, ToT, IS, and VC approaches can provide specific outcomes for poverty alleviation and a better fit between technology and the needs of potential users. The NPD approach can deliver similar outcomes if included during technology design with target populations (e.g. poor households) and technology-oriented approaches (ToT and FS). Using these complementarities and complementarity between approaches will help to fit design to users' needs and users' diversity (Altenburg, 2008; see D-Lab inclusive innovation for examples[6]). Aquaculture innovation may require II approaches to tailor the innovation to the users' needs, especially when the intervention happens in developing countries and targets small-scale farmers with limited capacity. However, when such approaches are used, methods to document stakeholder participation and involvement during the design of new technology need to be deployed and the organization of inclusiveness analysed. Structured frameworks to collect and analyse feedback from users (Sumberg et al., 2013) and other stakeholders involved in a technology design can yield interesting insights to identify the stakeholders' requirements and needs in order to develop ideal products (Bos and Grin, 2012; Elzen and Bos, 2016). Hence, the complementarity between those approaches can help to bridge the gap identified in Béné et al. (2016) – who stated that aquaculture is not accessible to the poor – and thus will help smallholder poor farmers to adopt aquaculture technologies.

Fostering interdisciplinary research and developing methodologies for better complementing different approaches could yield new insight to understand transformative processes in fast-developing and intensive aquaculture regions (e.g. Bangladesh, Egypt, Ecuador, or the Vietnamese Mekong Delta). It could also provide robust assessment and guide solutions to issues such as social sustainability.

5. Conclusion

This paper aimed to identify how innovation is studied in the aquaculture sector in terms of how it is conceptualized and managed and the main gaps within different bodies of relevant literature representing different approaches. Distinguishing how innovation is conceptualized by the studies analysed proved to be challenging, as an explicit description of innovation processes and management was often not the main purpose – rather it was to present a new technology or practice. The selected studies thus had different scopes and foci and provided knowledge about innovation in aquaculture from different angles, scales, and levels. Despite these analytical challenges, our review has clearly shown that the literature on innovation in aquaculture dominantly approaches innovation from a linear and technology-oriented perspective, and that systems and business and management approaches are less prevalent. The analysis of potential cross-fertilization suggests that using more than one perspective on innovation could yield richer insights on the dynamics of aquaculture innovation and help respond to complex problems. We therefore propose a reflection framework that points out complementarities in approaches to innovation in aquaculture aiming at better supporting innovation design and better understating innovation processes.

We expect technology-driven studies on innovation – and, related to this, technology-oriented innovation management approaches in aquaculture – to be important, now and in the future, because of the intrinsic structure of the research funding that supports projects

[6] https://d-lab.mit.edu/.

on small-scale aquaculture for poverty alleviation and local economic development in developing countries. Interventions and research are often deployed within a limited project timeframe for rapid and measurable outcomes at household level, rather than looking at institutional and organizational change of the overall sector. However, these may lead to technologies and practices that will have limited success and low adoption, or may have negative consequences in the long run. Hence, even if *Technology-driven approaches* (ToT and FS) have integrated some elements of systemic approaches, there appears to be scope for better integration of these approaches to generate technologies better adapted to context, or to better adapt the context to technologies. Multi-level perspective approaches to aquaculture innovation, found in SI or IS, could be integrated in the early steps of technology-driven research to better illustrate what needs to be implemented beyond technology to enable innovation and co-evolution between technology and context. Integrating elements of NPD approaches within a system perspective will support the design of technologies that fit the context or that will help change the context to embed the technology by integrating user and stakeholder feedback. In a similar vein, elements of II are rarely found, although they could help to better tailor the technology to the context of poor farmers or other specific target groups: this seems particularly relevant for South Asia and Africa, where numerous studies focus on incremental innovation at farm level and are framed within ToT or FS approaches.

Beyond informing approaches to better manage innovation targeted at the farm level, it seems that it is also necessary to integrate more systemic approaches to innovation to inform policymakers and development agencies dealing with overall sector development. For example, in Southeast Asia, the fast-growing aquaculture sector that yielded undesirable social and environmental impacts, as reported by research and non-governmental organizations, guided innovation research to more systemic approaches by looking at value chain, regulatory framework, and political and social dynamics. Similar approaches to innovation are needed in Africa, Latin America, or specific countries in Southeast Asia like Cambodia, where aquaculture is growing rapidly and where undesirable environmental and social impacts need to be anticipated by a better organization of sector transformation.

In conclusion, research on aquaculture would benefit from exploiting complementarities between different approaches to innovation and arriving at an approach that connects technology design with inducing systemic changes to embed technology, with the objective of understanding and providing solutions to complex problems relating to a fast-growing industry where issues are not only technical, but need to take into consideration social, ecological, and institutional dimensions of aquaculture innovation.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.aquaculture.2016.12.020.

Acknowledgments

This study forms part of the *Nutritious-system pond farming in Vietnam project*, funded by the Netherlands Organization for Scientific Research WOTRO Science for Global Development (NWO- WOTRO). The authors acknowledge the valuable support of Joke Webbink and Annemie Kersten of Wageningen University library in defining the search codes used in the Scopus and ASFA search engines.

References

Aarset, B., 1999. Aquacultural development, institution building and research and development policy: Norwegian salmon and Arctic char farming as cases. Aquac. Econ. Manag. 3, 177.

Abella, T.A., 2006. The role of public sector in genetics research and its partnership with private sector in Philippines. In: Acosta, B.O., Sevilleja, R.C., Gupta, M.V. (Eds.), Public and Private Partnerships in Aquaculture: A Case Study on Tilapia Research and Development. WorldFish Center Conf. Proc. 72, pp. 10–15 (72 pp.).

Acosta, B.O., Gupta, M.V., 2010. The genetic improvement of farmed tilapias project: impact and lessons learned. Success Stories Asian Aquac, pp. 149–171.

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D., Overy, P., 2016. Sustainability-oriented innovation : a systematic review. Int. J. Manag. Rev. 18, 180–205.

Aerni, P., 2004. Risk, regulation and innovation: the case of aquaculture and transgenic fish. Aquat. Sci. 66, 327–341.

Agbamu, J.U., Orhorhoro, W.C., 2007. Adoption of aquaculture management techniques in Delta State, Nigeria. J. Food Agric. Environ. 5, 243–246.

Agogué, M., Yström, A., Le Masson, P., 2013. Rethinking the role of intermediaries as an architect of collective exploration and creation of knowledge in open innovation. Int. J. Innov. Manag. 17 (2).

Ahmed, N., Flaherty, M.S., 2014. Opportunities for aquaculture in the ethnic Garo community of northern Bangladesh. Water Resour. Rural Dev. 3, 14–26.

Ahmed, N., Toufique, K.A., 2015. Greening the blue revolution of small-scale freshwater aquaculture in Mymensingh, Bangladesh. Aquac. Res. 46, 2305–2322.

Ahmed, N., Zander, K.K., Garnett, S.T., 2011. Socioeconomic aspects of rice-fish farming in Bangladesh: opportunities, challenges and production efficiency. Aust. Agric. Resour. Econ. 55, 199–219.

Åkerman, M., Kilpiö, A., Peltola, T., 2010. Institutional change from the margins of natural resource use: the emergence of small-scale bioenergy production within industrial forestry in Finland. Forest Policy Econ. 12 (3), 181–188.

Alexander, K.A., Potts, T.P., Freeman, S., Israel, D., Johansen, J., Kletou, D., Meland, M., Pecorino, D., Rebours, C., Shorten, M., Angel, D.L., 2015. The implications of aquaculture policy and regulation for the development of integrated multi-trophic aquaculture in Europe. Aquaculture 443, 16–23.

Altenburg, T., 2008. Building inclusive innovation systems in developing countries – why it is necessary to rethink the policy agenda. Proceeding of IV Globelics Conf. Mex. City, Sept. 22–24 2008, pp. 1–17.

Alvial, A., 2010. Challenges for developing emerging economies to engage in off-the- coast and offshore aquaculture: the perspective from a case study. In: Lovatelli, A., Aguilar-Manjarrez, J., Soto, D. (Eds.), Expanding Mariculture Farther Offshore: Technical, Environmental, Spatial and Governance Challenges. FAO Technical Workshop, 22–25 March 2010, Orbetello, Italy. FAO Fisheries and Aquaculture Proceedings No. 24. FAO, Rome, pp. 297–314.

Anh, P.T., Bush, S.R., Mol, A.P.J., Kroeze, C., Thi, P., Bush, S.R., Mol, A.P.J., Kroeze, C., 2011. The multi-level environmental governance of Vietnamese aquaculture: global certification, national standards, local cooperatives. J. Environ. Policy Plan. 13 (4), 373–397.

Anh, P.T., Bush, S.R., Mol, A.P.J., Kroeze, C., Thi, P., Bush, S.R., Mol, A.P.J., Kroeze, C., 2016. The multi-level environmental governance of Vietnamese aquaculture : global certification , national standards , local cooperatives. J. Environ. Policy Plan. 13 (4), 373–397.

Arksey, H., O'Malley, L., 2005. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8, 19–32.

Asche, F., Guttormsen, A.G., Tveteras, R., 1999. Environmental problems, productivity and innovations in Norwegian salmon aquaculture. Aquac. Econ. Manag. 3, 19–29.

Asche, F., Roll, K.H., Tveteras, R., 2012. Innovations and productivity performance in salmon aquaculture. IFIP Adv. Inf. Commun. Technol. 384, 620–627 (AICT).

Aslesen, H., 2004. Knowledge intensive service activities and innovation in the Norwegian aquaculture industry. STEP Rep. 53, 160.

Aslesen, H.W., 2007. The innovation system of Norwegian aquacultured salmonids 47. TIK Working Paper on Innovation Studies No. 20070606.

Aslesen, H., Isaksen, A., 2007. New perspectives on knowledge-intensive services and innovation. Geogr. Ann. Ser. B 89 (1), 45–58.

Ayele, S., Duncan, A., Larbi, A., Khanh, T.T., 2012. Enhancing innovation in livestock value chains through networks: lessons from fodder innovation case studies in developing countries. Sci. Public Policy 39 (3), 333–346.

Azim, M.E., Rahaman, M.M., Wahab, M.A., Asaeda, T., 2004. Periphyton-based pond polyculture system: a bioeconomic comparison of on-farm and on-station trials. Aquaculture 242, 381–396.

Barman, B.K., Little, D.C., 2006. Nile tilapia (*Oreochromis niloticus*) seed production in irrigated rice-fields in northwest Bangladesh-an approach appropriate for poorer farmers? Aquaculture 261, 72–79.

Barman, B., Little, D.C., 2011. Use of hapas to produce Nile tilapia (*Oreochromis niloticus* L.) seed in household food fish ponds: a participatory trial with small-scale farming households in northwest Bangladesh. Aquaculture 317, 214–222.

Barton, J.R., Fløysand, A., 2010. The political ecology of Chilean salmon aquaculture, 1982–2010: a trajectory from economic development to global sustainability. Glob. Environ. Chang. 20, 739–752.

Basiao, Z.U., Arago, A.L., Doyle, R.W., 2005. A farmer-oriented Nile tilapia, *Oreochromis niloticus* L., breed improvement in the Philippines. Aquac. Rep. 36, 113–119.

Baticados, D.B., Agbayani, R.F., Quinitio, E.T., 2014. Community-based technology transfer in rural aquaculture: the case of mud crab *Scylla serrata* nursery in ponds in northern Samar, central Philippines. Ambio 1047–1058.

Belton, B., Little, D.C., 2008. The development of aquaculture in central Thailand | domestic demand versus export-led production. J. Agrar. Chang. 8, 123–143.

Belton, B., Little, D.C., 2011. Immanent and interventionist inland Asian aquaculture development and its outcomes. Dev. Policy Rev. 29, 459–484.

Belton, B., Le, S.X., Little, D.C., 2008. The development and status of catfish seed production systems in Vietnam. PMI2 project report. 49.

Belton, B., Turongruang, D., Bhujel, R., Little, D., 2009. The history, status, and future prospects of monosex tilapia culture in Thailand. Aquac. Asia XIV, 16–19.

Belton, B., Little, D.C., Sinh, L.X., 2011. The social relations of catfish production in Vietnam. Geoforum 42, 567–577.

Béné, C., Arthur, R., Norbury, H., Allison, E.H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S.H., Troell, M., Williams, M., 2016.

Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Dev. 79, 177–196.
Berkes, F., Folke, C., 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge.
Biggs, S.D., 1995. Farming systems research and rural poverty: relationships between context and content. Agric. Syst. 47, 161–174.
Bogne Sadeu, C., Mikolasek, O., Pouomogne, V., Eyango, M.T., 2013. The use of wild catfish (*Clarias* spp.) in combination with Nile tilapia (*Oreochromis niloticus* L.) in western Cameroon: technical performances, interests, and limitations. J. Appl. Aquac. 25, 359–368.
Borgen, S.O., Aarset, B., 2016. Participatory innovation: lessons from breeding cooperatives. Agric. Syst. 145, 99–105.
Bos, A.P., Grin, J., 2012. Reflexive interactive design as an instrument for dual track governance. In: Barbier, M., Elzen, B.E. (Eds.), System Innovations, Knowledge Regimes, and Design Practices Towards Transitions for Sustainable Agriculture. INRA-SAD, Paris.
Bremer, S., Millar, K., Wright, N., Kaiser, M., 2015. Responsible techno-innovation in aquaculture: employing ethical engagement to explore attitudes to GM salmon in northern Europe. Aquaculture 437, 370–381.
Browdy, C.L., Hulata, G., Liu, Z.J., Allan, G.L., Sommerville, C., Andrade, T.P., Pereira, R., Yarish, C., Shpigel, M., Chopin, T., Robinson, S., Avnimelech, Y., Lovatelli, A., 2012. Novel and emerging technologies: can they contribute to improving aquaculture sustainability. Proc. Glob. Conf. Aquac. 2010. Farming Waters People Food. 1, pp. 149–191.
Brummett, R.E., Jamu, D.M., 2011. From researcher to farmer: partnerships in integrated aquaculture – agriculture systems in Malawi and Cameroon. Int. J. Agric. Sustain. 9, 282–289.
Brummett, R.E., Noble, R.P., Chikafumbwa, F.J.K., 1996. Farmer-scientist research partnerships for integrated agriculture-aquaculture. Aquaculture and Fisheries Document No 71. Bunda College of Agriculture, University of Malawi.
Brummett, R.E., Lazard, J., Moehl, J., 2008. African aquaculture: realizing the potential. Food Policy 33, 371–385.
Brummett, R.E., Gockowski, J., Pouomogne, V., Muir, J., 2011. Targeting agricultural research and extension for food security and poverty alleviation: a case study of fish farming in central Cameroon. Food Policy 36, 805–814.
Bush, S.R., Belton, B., 2012. Out of the factory and into the fish pond can certification transform Vietnamese *Pangasius*? Food Pract. Transit. Chang. Food Consum. Retail Prod. Age Reflexive Mod, pp. 257–290
Bush, S.R., Marschke, M.J., 2014. Making social sense of aquaculture transitions. Ecol. Soc. 19, 50.
Bush, S.R., Oosterveer, P., Bailey, M., Mol, A.P.J., 2015. Sustainability governance of chains and networks: a review and future outlook. J. Clean. Prod. 107, 8–19.
Bustos, B., 2015. Moving on? Neoliberal continuities through crisis: the case of the Chilean salmon industry and the ISA virus. Environ. Plann. C. Gov. Policy 33, 1361–1375.
Carlsson, B., 1995. Technological Systems and Economic Performance: The Case of Factory Automation. Kluwer Academic Publishers, Dordrecht.
Cerf, M., Jeuffroy, M.-H., Prost, L., Meynard, J.M., 2012. Participatory design of agricultural decision support tools: taking account of the use situations. Agron. Sustain. Dev. 32 (4), 899–910.
Chesbrough, H.W., 2003. Open Innovation: The New Imperative for Creating and Profiting From Technology. Harvard Business Review Press, Boston, MA.
De Silva, S.S., Nguyen, T.T.T., Turchini, G.M., Amarasinghe, U.S., Abery, N.W., 2009. Alien species in aqua-culture and biodiversity: a paradox in food production. Ambio 38, 24–28.
Deutsch, L., Gräslund, S., Folke, C., Troell, M., Huitric, M., Kautsky, N., Lebel, L., 2007. Feeding aquaculture growth through globalization: exploitation of marine ecosystems for fishmeal. Glob. Environ. Chang. 17, 238–249.
Devaux, A., Horton, D., Velasco, C., Thiele, G., Lopez, G., Bernet, T., Reinoso, I., Ordinola, M., 2009. Collective action for market chain innovation in the Andes. Food Policy 34 (1), 31–38.
Dey, M.M., Prein, M., Mahfuzul Haque, A.B.M., Sultana, P., Cong Dan, N., Van Hao, N., 2005. Economic feasibility of community-based fish culture in seasonally flooded rice fields in Bangladesh and Vietnam. Aquac. Econ. Manag. 9, 65–88.
Dey, M.M., Paraguas, F.J., Kambewa, P., Pemsl, D.E., 2010. The impact of integrated aquaculture-agriculture on small-scale farms in southern Malawi. Agric. Econ. 41, 67–79.
Dey, M.M., Spielman, D.J., Haque, A.B.M.M., Rahman, M.S., Valmonte-Santos, R., 2013. Change and diversity in smallholder rice–fish systems: recent evidence and policy lessons from Bangladesh. Food Policy 43, 108–117.
Diana, J.S., Egna, H.S., Chopin, T., Peterson, M.S., Cao, L., Pomeroy, R., 2013. Responsible aquaculture in 2050: valuing local conditions and human innovations will be key to success. Bioscience 63, 255–262.
Doloreux, D., Isaksen, A., Aslesen, H.W., Melançon, Y., 2009. A comparative study of the aquaculture innovation systems in Quebec's coastal region and Norway. Eur. Plan. Stud. 17, 963–981.
Edquist, C., 1997. Systems of Innovation – Technologies, Institutions and Organizations. Printer Publishers, London and Washington.
Elzen, B., Bos, B., 2016. The RIO approach: design and anchoring of sustainable animal husbandry systems. Technol. Forecast. Soc. Chang. http://dx.doi.org/10.1016/j.techfore.2016.05.023.
Elzen, B., Wieczorek, A., 2005. Transitions towards sustainability through system innovation. Technol. Forecast. Soc. Chang. 72, 651–661 (6 SPEC. ISS.).
Elzen, B., Barbier, M., Cerf, M., Grin, J., 2012. Stimulating transitions towards sustainable farming systems. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research Into the 21st Century: A New Dynamic. Springer, Dordrecht, pp. 431–455.
FAO, 2012. The State of World Fisheries and Aquaculture 2012. Rome, FAO.
FAO, 2013. FAOSTAT (Food and Agriculture Organization, Rome). 2013.
Fast, A.W., Menasveta, P., 2000. Some recent issues and innovations in marine shrimp pond culture. Rev. Fish. Sci. 8, 151–233.
Fichter, K., 2009. Innovation communities: the role of networks of promotors in open innovation. R&D Manag. 39 (4), 357–371.
Fløysand, A., Haarstad, H., Barton, J., 2010. Global economic imperatives, crisis generation and local spaces of engagement in the Chilean aquaculture industry. Nor. Geogr. Tidsskr. 64, 199–210.
Foran, T., Butler, J.R.A., Williams, L.J., Wanjura, W.J., Hall, A., Carter, L., Carberry, P.S., 2014. Taking complexity in food systems seriously: an interdisciplinary analysis. World Dev. 61, 85–101.
Foster, D., Demaine, H., 2005. The role of extension in effecting on-farm practice change for controlling shrimp disease. In: Walker, P., Lester, R., Bondad-Reantaso, M.G. (Eds.), Diseases in Asian Aquaculture V. Fish Health Section, Asian Fisheries Society, Manila, pp. 589–601.
Galappaththi, E.K., Berkes, F., 2014. Institutions for managing common-pool resources: the case of community-based shrimp aquaculture in northwestern Sri Lanka. Marit. Stud. 13, 13.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31 (8–9), 1257–1274.
Gereffi, G., Humphrey, J., Sturgeon, T.J., 2005. The governance of global value chains. Rev. Int. Polit. Econ. 12, 78–104.
Giap, D.H., Garden, P., Lebel, L., 2010. Enabling sustainable shrimp aquaculture: narrowing the gaps between science and policy in Thailand. In: Lebel, L., et al. (Eds.), Sustainable Production Consumption Systems Knowledge, Engagement and Practice, pp. 123–144.
Gibbon, P., Ponte, S., 2005. Trading Down: Africa, Value Chains, and the Global Economy. Temple University Press, Philadelphia, PA.
Gibbon, P., Bair, J., Ponte, S., 2008. Governing global value chains: an introduction. Econ. Soc. 37 (3), 315–338.
Grieve, B., Bushell, M., Lant, M., Georghiou, L., Malik, K., 2009. Changing the rules of the game for future agriculture, the university innovation centre (UIC) model. PICMET Portl. Int. Cent. Manag. Eng. Technol. Proc., pp. 288–298.
Grin, G., Rotmans, J., Schot, J., Geels, F., Loorbach, D., 2010. Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change. Routledge, London, UK.
Groot Koerkamp, P.W.G., Bos, A.P., 2008. Designing complex and sustainable agricultural production systems: an integrated and reflexive approach for the case of table egg production in the Netherlands. NJAS – Wageningen J. Life Sci. 55, 113–138.
Gupta, M.V., Sollows, J.D., Mazid, M.A., Rahman, A., Hussain, M.G., Dey, M.M., 1998. Integrating aquaculture with rice farming in Bangladesh: feasibility and economic viability, its adoption and impact. ICLARM Tech. Rep. 55 (90 pp.).
Gupta, J., Pouw, N.R.J., Ros-Tonen, M.A.F., 2015. Towards an elaborated theory of inclusive development. Eur. J. Dev. Res. 27 (4), 541–559.
Gurung, T.B., Mulmi, R.M., Kalyan, K.C., Wagle, G., Pradhan, G.B., Upadhayaya, K., Rai, A.K., 2010. Cage fish culture: an alternative livelihood option for communities displaced by reservoir impoundment in Kulekhani, Nepal. In: De Silva, S.S., Davy, F.B. (Eds.), Success Stories in Asian Aquaculture, Success Stories in Asian Aquaculture, pp. 85–102.
Ha, T.T.T., Bush, S.R., 2010. Transformations of Vietnamese shrimp aquaculture policy: empirical evidence from the Mekong Delta. Environ. Plann. C. Gov. Policy 28, 1101–1119.
Haasnoot, T., Kraan, M., Bush, S.R., 2016. Fishing gear transitions: lessons from the Dutch flatfish pulse trawl. ICES J. Mar. Sci. 73 (4), 1235–1243.
Hall, D., 2004. Explaining the diversity of southeast Asian shrimp aquaculture. J. Agrar. Chang. 4, 315–335.
Hall, A., Janssen, W., Pehu, E., Rajalahti, R., 2006. Enhancing Agricultural Innovation: How to Go beyond the Strengthening of Research Systems. World Bank, Washington, DC.
Hamilton, S., 2013. Assessing the role of commercial aquaculture in displacing mangrove forest. Bull. Mar. Sci. 89, 585–601.
Hansen, E., Nybakk, E., Panwar, R., 2014. Innovation insights from North American forest sector research: a literature review. Forests 5 (6), 1341–1355.
Haque, M.M., Little, D.C., Barman, B.K., Wahab, M.A., 2010. The adoption process of ricefield-based fish seed production in northwest Bangladesh: an understanding through quantitative and qualitative investigation. J. Agric. Educ. Ext. 16, 161–177.
Haque, M.M., Little, D.C., Barman, B.K., Wahab, M.A., Telfer, T.C., 2014. Impacts of decentralized fish fingerling production in irrigated rice fields in northwest Bangladesh. Aquac. Res. 45, 655–674.
Haque, M.M., Alam, M.R., Alam, M.M., Basak, B., Sumi, K.R., Belton, B., Jahan, K.M.-E., 2015. Integrated floating cage aquageoponics system (IFCAS): an innovation in fish and vegetable production for shaded ponds in Bangladesh. Aquac. Rep. 2, 1–9.
Haque, M.M., Belton, B., Alam, M.M., Ahmed, A.G., Alam, M.R., 2016. Reuse of fish pond sediments as fertilizer for fodder grass production in Bangladesh: potential for sustainable intensification and improved nutrition. Agric. Ecosyst. Environ. 216, 226–236.
Hargreaves, J.A., 2002. Channel catfish farming in ponds: lessons from a maturing industry. Rev. Fish. Sci. 10, 499–528.
Harrison, E., 1996. Digging fish ponds: perspectives on motivation in Luapula Province, Zambia. Hum. Organ. 55, 270–278.
Hasan, M.R., 2012. Transition from low-value fish to compound feeds in marine cage farming in Asia. FAO Fisheries and Aquaculture Technical Paper No 573. FAO, Rome (192 pp.).
Heeks, R., Foster, C., Nugroho, Y., 2014. New models of inclusive innovation for development. Innov. Dev. 4, 175–185.

Henderson, R.M., Clark, K.B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Adm. Sci. Q. 35 (1), 9–31.

Holling, C.S., 1978. Adaptive Environmental Assessment and Management. Wiley, Chichester.

Ingram, J., 2015. Framing niche-regime linkage as adaptation: an analysis of learning and innovation networks for sustainable agriculture across Europe. J. Rural. Stud. 40, 59–75.

Islam, M.S., 2008. From pond to plate: towards a twin-driven commodity chain in Bangladesh shrimp aquaculture. Food Policy 33 (3), 209–223.

Islam, M.S., Karim, M., Nandeesha, M.C., Khan, M.H., Chinabut, S., Lilley, J.H., 2003. Farmer-based investigation of treatments for ulcerative disease in polyculture carp ponds in Bangladesh. Asian Fish. Sci. 16, 327–338.

Jarrett, F.G., 1985. Sources and models of agricultural innovation in developed and developing countries. Agric. Adm. 18, 217–234.

Jarský, V., 2015. Analysis of the sectoral innovation system for forestry of the Czech Republic. Does it even exist? Forest Policy Econ. 59, 56–65.

Jespersen, K.S., Kelling, I., Ponte, S., Kruijssen, F., 2014. What shapes food value chains? Lessons from aquaculture in Asia. Food Policy 49, 228–240.

Joffre, O., Sheriff, N., 2011. Condition for Collective Action: Understanding Factors Supporting and Constraining Community-based Fish Culture in Bangladesh, Cambodia and Vietnam: WorldFish Center Studies and Review 2011–21. The WorldFish Center, Penang, Malaysia (46 pp.).

Karim, M., Little, D.C., Kabir, S., Verdegem, M.J.C., Telfer, T., Wahab, 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, 225–235.

Karim, M., Sarwer, R.H., Phillips, M., Belton, B., 2014. Profitability and adoption of improved shrimp farming technologies in the aquatic agricultural systems of southwestern Bangladesh. Aquaculture 428–429.

Karim, M., Keus, H.J., Ullah, M.H., Kassam, L., Phillips, M., Beveridge, M., 2016. Investing in carp seed quality improvements in homestead aquaculture: lessons from Bangladesh. Aquaculture 453, 19–30.

Katzy, B., Turgut, E., Holzmann, T., Sailer, K., 2013. Innovation intermediaries: a process view on open innovation coordination. Tech. Anal. Strat. Manag. 25 (3), 295–309.

Kilelu, C.W., Klerkx, L., Leeuwis, C., 2013. Unravelling the role of innovation platforms in supporting co-evolution of innovation: contributions and tensions in a smallholder dairy development programme. Agric. Syst. 118, 65–77.

Klerkx, L., Van Mierlo, B., Leeuwis, C., 2012. Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research Into the 21st Century: The New Dynamic, pp. 457–483.

Klerkx, L., Adjei-Nsiah, S., Adu-Acheampong, R., Saïdou, A., Zannou, E., Soumano, L., Sakyi-Dawson, O., van Paassen, A., Nederlof, S., 2013. Looking at agricultural innovation platforms through an innovation champion lens: an analysis of three cases in West Africa. Outlook Agric. 42, 185–192.

Klinger, D., Naylor, R., 2012. Searching for solutions in aquaculture: charting a sustainable course. Annu. Rev. Environ. Resour. 37, 247–276.

Kripa, V., Mohamed, K., 2008. Green mussel, *Perna viridis*, farming in Kerala, India – technology diffusion process and socioeconomic impacts. J. World Aquacult. Soc. 39, 612–624.

Kubeczko, K., Rametsteiner, E., Weiss, G., 2006. The role of sectoral and regional innovation systems in supporting innovations in forestry. Forest Policy Econ. 8 (7), 704–715.

Kumar, N., Quisumbing, A.R., 2010. Access, adoption, and diffusion: understanding the long-term impacts of improved vegetable and fish technologies in Bangladesh. IFPRI Discuss. Pap. 00995, pp. 1–35.

Lebel, L., Tri, N.H., Saengnoree, A., Pasong, S., Buatama, U., Thoa, L.K., 2002. Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathways to ecological, social, and economic sustainability? Ambio 31, 311–323.

Lebel, L., Garden, P., Luers, A., Manuel-Navarrete, D., Giap, D.H., 2009. Knowledge and innovation relationships in the shrimp industry in Thailand and Mexico. Proc. Natl. Acad. Sci. U. S. A. 113 (17), 4585–4590.

Lebel, L., Mungkung, R., Gheewala, S.H., Lebel, P., 2010. Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. Environ. Sci. Pol. 13, 291–302.

Leeuwis, C., van den Ban, A., 2004. Communication for Rural Innovation: Rethinking Agricultural Extension. Blackwell Science, Oxford.

Levac, D., Colquhoun, H., O'Brien, K.K., 2010. Scoping studies: advancing the methodology. Implement. Sci. 5, 69.

Liao, I.C., Hsu, Y.-K., Lee, W.C., 2002. Technical innovations in eel culture systems. Rev. Fish. Sci. 10, 433–450.

Little, D.C., Surintaraseree, P., Innes-Taylor, N., 1996. Fish culture in rainfed rice fields of northeast Thailand. Aquaculture 140, 295–321.

Loorbach, D., Rotmans, J., 2010. The practice of transition management: examples and lessons from four distinct cases. Futures 42, 237–246.

Lundvall, B.A., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

Malerba, F., 2002. Sectoral systems of innovation and production. Res. Policy 31, 247–264.

Malik, K., Georghiou, L., Grieve, B., 2011. Developing new technology platforms for new business models: Syngenta's partnership with the university of Manchester. Res. Manag. 54, 24–31.

Markus Perkmann, K.W., 2007. University-industry relationships and open innovation: towards a research agenda. Int. J. Manag. Rev. 9 (4), 259–280.

Martinez, P.R., Molnar, J., Trejos, E., Meyer, D., Triminio Meyer, S., Tollner, W., 2004. Cluster membership as a competitive advantage in aquacultural development: case study of tilapia producers in Olancho, Honduras. Aquac. Econ. Manag. 8, 194–281.

Mbabu, A., Hall, A., 2012. Capacity Building for Agricultural Research for Development: Lessons From Practice in Papua New Guinea. United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT), Maastricht.

Meynard, J.-M., 2016. Designing coupled innovations for the sustainability transition of agrifood systems. Agric. Syst. http://dx.doi.org/10.1016/j.agsy.2016.08.002.

Miyata, S., Manatunge, J., 2004. Knowledge sharing and other decision factors influencing adoption of aquaculture in Indonesia. Int. J. Water Resour. Dev. 20, 523–536.

Montagna, F., 2011. Decision-aiding tools in innovative product development contexts. Res. Eng. Des. 22, 63–86.

Murshed-e-Jahan, K., Pemsl, D.E., 2011. The impact of integrated aquaculture – agriculture on small-scale farm sustainability and farmers' livelihoods: experience from Bangladesh. Agric. Syst. 104, 392–402.

Murshed-e-Jahan, K., Beveridge, M.C.M., Brooks, A., 2008. Impact of long-term training and extension support on small-scale carp polyculture farms of Bangladesh. J. World Aquacult. Soc. 39, 441–453.

Myers, M.L., Durborow, R.M., 2011. Hierarchical aquacultural hazard controls for inherently safer work. Am. Soc. Agric. Biol. Eng. Annu. Int. Meet. 2011, ASABE 2011. 3, pp. 2141–2159.

Nadvi, K., 2008. Global standards, global governance and the organization of global value chains. J. Econ. Geogr. 8, 323–343.

Nandeesha, M.C., 2007. Asian experience on farmer's innovation in freshwater fish seed production and nursing and the role of women. In: Bondad-Reantaso, M.G. (Ed.), Assessment of Freshwater Fish Seed Resources for Sustainable Aquaculture. FAO Fisheries Technical Paper. No. 501. Rome, FAO. 2007, pp. 581–602 (628 pp.).

Nandeesha, M.C., Halwart, M., Gómez, R.G., Alvarez, C.A., Atanda, T., Bhujel, R., Bosma, R., Giri, N.A., Hahn, C.M., Little, D., Luna, P., Márquez, G., 2012. Supporting farmer innovations, recognizing indigenous knowledge and disseminating success stories novel and emerging technologies: can they contribute to improving aquaculture sustainability. Proc. Glob. Conf. Aquac. 2010. Farming Waters People Food. 1, pp. 823–874.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., et al., 2000. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.

Naylor, R., Hindar, K., Fleming, I.A., Goldburg, R., Williams, S., et al., 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. Bioscience 55, 427–437.

Ndah, H.T., Knierim, A., Ndambi, O.A., 2011. Fish pond aquaculture in Cameroon: a field survey of determinants for farmers' adoption behaviour. J. Agric. Educ. Ext. 17, 309–323.

Nelson, R., Rosenberg, N., 1993. Technical innovation and national systems. In: Nelson, R. (Ed.), National Innovation Systems. Oxford University Press, Oxford.

Nhan, D.K., Phong, L.T., Verdegem, M.J.C., Duong, L.T., Bosma, R.H., Little, D.C., 2007. Integrated freshwater aquaculture, crop and livestock production in the Mekong delta, Vietnam: determinants and the role of the pond. Agric. Syst. 94, 445–458.

Ni, D.V., Phat, T.D., Lu, T., Tung, P.B.V., Ben, D.C., Vu, D.H., Thai, P.H., Giang, P.H., Tuong, T.P., 2010. Diversified cropping systems in a coastal province of the Mekong Delta, Vietnam: from testing to outscaling. In: Hoanh, C.T., Szuster, B.W., Suan-Pheng, K., Ismail, A.M., Noble, A.D. (Eds.), Tropical Deltas and Coastal Zones: Food Production, Communities, and Environment at the Land-water Interface (496 pp.).

Nyaupane, N.P., Gillespie, J.M., 2011. Louisiana crawfish farmer adoption of best management practices. J. Soil Water Conserv. 66, 61–70.

Nybakk, E., Hansen, E., 2008. Entrepreneurial attitude, innovation and performance among Norwegian nature-based tourism enterprises. Forest Policy Econ. 10, 473–479.

Nybakk, E., Crespell, P., Hansen, E., 2011. Climate for innovation and innovation strategy as drivers for success in the wood industry: moderation effects of firm size, industry sector, and country of operation. Silva Fenn. 45, 415–430.

Oguamanam, C., 2013. Open innovation in plant genetic resources for food and agriculture. Chicago-Kent J. Intellect. Prop. 13.

Olsson, P., Galaz, V., Boonstra, W.J., 2014. Sustainability transformations: a resilience perspective. Ecol. Soc. 19 (4), 1.

Paez-Osuna, F., 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environ. Manag. 28, 131–140.

Page, A.L., Schirr, G.R., 2008. Growth and development of a body of knowledge: 16 years of new product development research, 1989–2004. J. Prod. Innov. Manag. 25, 233–248.

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 46 (11), 1407–1424.

Pant, L.P., Hambly-Odame, H., 2009. Innovation systems in renewable natural resource management and sustainable agriculture: a literature review. Afr. J. Sci. Technol. Innov. Dev. 1 (1), 103–135.

Pant, J., Barman, B.K., Murshed-e-Jahan, K., Belton, B., Beveridge, M., 2014. Can aquaculture benefit the extreme poor? A case study of landless and socially marginalized Adivasi (ethnic) communities in Bangladesh. Aquaculture 418–419, 1–10.

Pant, L.P., Adhikari, B., Bhattarai, K.K., 2015. Adaptive transition for transformations to sustainability in developing countries. Curr. Opin. Environ. Sustain. 14, 206–212.

Paul, B.G., Vogl, C.R., 2013. Organic shrimp aquaculture for sustainable household livelihoods in Bangladesh. Ocean Coast. Manag. 71, 1–12.

Peacock, S.J., Krkosek, M., Proboszcz, S., Orr, C., Lewis, M.A., 2013. Cessation of a salmon decline with control of parasites. Ecol. Appl. 23, 606–620.

Pietrobelli, C., Rabellotti, R., 2009. The global dimension of innovation systems: linking innovation systems and global value chains. Handbook of Innovation Systems and Developing Countries: Building Domestic Capabilities in a Global Setting, pp. 214–238.

Pouomogne, V., Brummett, R.E., Gatchouko, M., 2010. Impacts of aquaculture development projects in western Cameroon. J. Appl. Aquac. 22, 93–108.

Prasad, S., Bista, J.D., Jalari, G.B., Acharya, D.R., 2012. In: Shrestha, M.K., Pant, J. (Eds.), Low-cost small-scale cage culture with grass carp (*Ctenopharyngodon idella*) for generating higher income for the poor. 2012. Small-scale Aquaculture for Rural Livelihoods: Proceedings of the National Symposium on Small-scale Aquaculture for Increasing Resilience of Rural Livelihoods in Nepal. Institute of Agriculture and Animal Science, Tribhuvan University, Rampur, Chitwan, Nepal, and The WorldFish Center, Penang, Malaysia (191 pp.).

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean Coast. Manag. 49, 531–545.

Rametsteiner, E., Weiss, G., 2006. Innovation and innovation policy in forestry: linking innovation process with systems models. Forest Policy Econ. 8 (7), 691–703.

Rauniyar, G.P., 1998. Adoption of management and technological practices by fishpond operators in Nepal. Aquac. Econ. Manag. 2, 89–99.

Rico, A., Satapornvanit, K., Haque, M.M., Min, J., Nguyen, P.T., Telfer, T.C., van den Brink, P.J., 2012. Use of chemicals and biological products in Asian aquaculture and their potential environmental risks: a critical review. Rev. Aquac. 4, 75–93.

Roep, D., Van der Ploeg, J.D., Wiskerke, J.S.C., 2003. Managing technical-institutional design processes: some strategic lessons from environmental co-operatives in The Netherlands. NJAS: Wageningen J. Life Sci. 51 (1/2), 195–217.

Rogers, E.M., 1995. Diffusion of Innovations. Free Press, New York.

Roos, N., Wahab, M.A., 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 Nutr. Bull. 28, 280–293.

Rosendal, G.K., Olesen, I., Tvedt, M.W., 2013. Evolving legal regimes, market structures and biology affecting access to and protection of aquaculture genetic resources. Aquaculture 402–403, 97–105.

Ros-Toonen, M.A.F., Van Leynseele, Y.-P.B., Laven, A., Sunderland, T., 2015. Landscapes of social inclusion: inclusive value-chain collaboration through the lenses of food sovereignty and landscape governance. Eur. J. Dev. Res. 27 (4), 523–540.

Rotmans, J., Kemp, R., Van Asselt, M., 2001. More evolution than revolution: transition management in public policy. Foresight 3 (1), 15–31.

Rowena, M., 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in the Philippines. In: Hasan, M.R., New, M.B. (Eds.), On-farm Feeding and Feed Management in Aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 583. FAO, Rome, pp. 131–158.

Saguin, K., 2015. Blue revolution in a commodity frontier: ecologies of aquaculture and agrarian change in Laguna Lake, Philippines. J. Agrar. Chang. http://dx.doi.org/10.1111/joac.12114.

Sampson, G.S., Sanchirico, J.N., Roheim, C.A., Bush, S.R., Taylor, J.E., Allison, E.H., Anderson, J.L., Ban, N.C., Fujita, R., Jupiter, S., Wilson, J.R., 2015. Secure sustainable seafood from developing countries: require improvements as conditions for market access. Science 348 (6234), 504–506.

Sandvold, H.N., Tveterås, R., 2014. Innovation and productivity growth in Norwegian production of juvenile salmonids. Aquac. Econ. Manag. 18, 149–168.

Sankaran, J.K., Suchitra Mouly, V., 2006. Value-chain innovation in aquaculture: insights from a New Zealand case study. R&D Manag. 36, 387–401.

Schot, J., Geels, F.W., 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Tech. Anal. Strat. Manag. 20, 537–554.

Schut, M., Rodenburg, J., Klerkx, L., van Ast, A., Bastiaans, L., 2014. Systems approaches to innovation in crop protection. A systematic literature review. Crop. Prot. 56, 98–108.

Sinclair, K., Curtis, A., Mendham, E., Mitchell, M., 2014. Can resilience thinking provide useful insights for those examining efforts to transform contemporary agriculture? Agric. Hum. Values 31 (3), 371–384.

Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41, 1025–1036.

Srinath, K., Sridhar, M., Kartha, P.N.R., Mohanan, A.N., 2000. Group farming for sustainable aquaculture. Ocean Coast. Manag. 43, 557–571.

Stevenson, J.R., Irz, X., 2009. Is aquaculture development an effective tool for poverty alleviation? A review of theory and evidence. Cah. Agric. 18, 292–299.

Stone, I.J., Benjamin, J.G., Leahy, J., 2011. Applying innovation theory to Maine's logging industry. J. For. 109 (8), 462–469.

Sumberg, J., Reece, D., 2004. Agricultural research through a new product development lens. Exp. Agric. 40, 295–314.

Sumberg, J., Heirman, J., Raboanarielina, C., Kaboré, A., 2013. From agricultural research to “product development”: what role for user feedback and feedback loops? Outlook Agric. 42, 233–242.

Swaans, K., Boogaard, B., Bendapudi, R., Taye, H., Hendrickx, S., Klerkx, L., 2014. Operationalizing inclusive innovation: lessons from innovation platforms in livestock value chains in India and Mozambique. Innov. Dev. 4, 239–257.

Tain, F.H., Diana, J.S., 2007. Impacts of extension practice: lessons from small farm-based aquaculture of Nile tilapia in northeastern Thailand. Soc. Nat. Resour. 20:583–595. http://dx.doi.org/10.1080/08941920601171824.

Tango-Lowy, T., Robertson, R.A., 2002. Predisposition toward adoption of open ocean aquaculture by northern New England's inshore, commercial fishermen. Hum. Organ. 61, 240–251.

Tenkorang, A., Yeboah-Agyepong, M., Buamah, R., Agbo, N.W., Chaudhry, R., Murray, A., 2012. Promoting sustainable sanitation through wastewater-fed aquaculture: a case study from Ghana. Water Int. 37, 831–842.

Theodorakopoulos, N., Sánchez Preciado, D.J., Bennett, D., 2012. Transferring technology from university to rural industry within a developing economy context: the case for nurturing communities of practice. Technovation 32, 550–559.

Theodorou, J.A., Perdikaris, C., Filippopoulos, N.G., 2015. Evolution through innovation in aquaculture: a critical review of the Greek mariculture industry. J. Appl. Aquac. 27, 160–181.

Thompson, P., Roos, N., Sultana, P., Thilsted, S.H., 2002. Changing significance of inland fisheries for livelihoods and nutrition in Bangladesh. J. Crop. Prod. 6, 319–337.

Thompson, P.M., Firoz Khan, A.K.M., Sultana, P., 2006. Comparison of aquaculture extension impacts in Bangladesh. Aquac. Econ. Manag. 10, 15–31.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D., 2001. Forecasting agriculturally driven global environmental change. Science 292, 281–284.

Tran, N., Bailey, C., Wilson, N., Phillips, M., 2013. Governance of global value chains in response to food safety and certification standards : the case of shrimp from Vietnam. World Dev. 45, 325–336.

Trienekens, J.H., 2011. Agricultural value chains in developing countries a framework for analysis. Int. Food Agribus. Manag. Rev. 14 (2), 51–82.

Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., Arrow, K.J., Barrett, S., Crépin, A.-S., Ehrlich, P.R., Gren, Å., Kautsky, N., Levin, S.A., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Walker, B.H., Xepapadeas, T., de Zeeuw, A., 2014. Does aquaculture add resilience to the global food system? Proc. Natl. Acad. Sci. 111, 13257–13263.

Ulrich, K.T., Eppinger, S.D., 2004. Product Design and Development. McGraw-Hill, New York.

Vandergeest, P., Flaherty, M., Miller, P., 1999. A political ecology of shrimp aquaculture in Thailand. Rural. Sociol. 64, 573–596.

Wetengere, K., 2011. Socio-economic factors critical for intensification of fish farming technology. A case of selected villages in Morogoro and Dar es Salaam regions, Tanzania. Aquac. Int. 19, 33–49.

Xie, Z., Hall, J., Mccarthy, I.P., Skitmore, M., Shen, L., 2016. Technovation standardization efforts: the relationship between knowledge dimensions, search processes and innovation outcomes. Technovation 48–49, 69–78.