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

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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).

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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/).