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Luigi Piper, Daniele Arduini

BUSINESS MODEL AND SUSTAINABILITY-LED INNOVATIONS

A case study on the Integrated Multitrophic Aquaculture

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to Adriana Giangrande,
who has given the sea and research her passion,
brilliance, and a lifetime of dedication.
May she continue to explore, discover, and guide those
who, thanks to her, have learned to see beyond.

BUSINESS MODEL AND SUSTAINABILITY-LED INNOVATIONS

A case study on the Integrated Multitrophic Aquaculture

Chapter 1

Introduction

Luigi Piper, Daniele Arduini

The growing interest for aquariums and color ornamental fish represents a part of consumers' luxury and green lifestyle but it risks being an unsustainable choice for the marine environment, mainly due to the damage caused to the coral reef ecosystem. This harm could or, better, should be remedied with the implementation of sustainable innovations in the sector.

Actually, it is forecasted that the global reef aquarium market will grow from USD 5.05 billion in 2024 to USD 5.5 billion in 2025, registering a compound annual growth rate (CAGR) of 8.9%. Furthermore, it is expected to reach USD 7.52 billion by 2029, maintaining a CAGR of 8.2% during the forecast period (The Business Research Company, 2025), while the global ornamental fish market was valued at USD 6.7 billion in 2024, it is projected to reach USD 12 billion by 2033, growing at a CAGR of 6.78% during the forecast period (IMARC Group, 2025).

The trade is to some extent controversial, and it is deemed to be one of the contributors to the demise of coral reef ecosystems (Newton *et al.*, 2007). First, damages are mainly related to the employment of incorrect and destructive collection techniques (*e.g.*, use of chemicals, hammers, crowbars) leading to a direct habitat loss. In fact, ornamental species supplying the USA and EU markets are mostly collected on coral reefs and imported from the Coral Triangle region, especially from Indonesia and the Philippines (Rhyne *et al.*, 2012; Watson *et al.*, 2023). Second, selective removal of target species (*e.g.*, based on sex and life stage) can compromise the reproductive capability of the species or stress non-target species impairing the coral reef ecosystem balance (Hamilton & Matawai, 2006). Third, the total volume, taxonomic and geographic origin of the live specimens used in marine aquaria are not fully known (Biondo & Calado, 2021). The aquarium industry deals in a variety of invertebrates in addition to fish (Olivotto *et al*., 2011), many of which are sessile species, such as polychaetes from the Sabellidae and Serpulidae families, also known as fan worms and coco worms, respectively (Murray *et al*., 2012; 2013).

Many countries have employed several management plans to monitor the coral wildlife trade and protect reef ecosystems both at international and regional level (Ezekiel, 2018). Globally, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has the aim to protect several types of fishes, hard/soft corals and giant clams threatened with extinction but, it is unknown if the majority of aquarium species are vulnerable to exploitation, thus resulting as an inappropriate tool for the protection of certain species. In addition, coral reefs under climate changes are facing recurrent mass bleaching and mortality events (Hughes *et al.,* 2017; Sully *et al*., 2019). The impoverishment of coral reefs has prompted restrictive legislation and use of innovative methods, such as aquaculture, to reduce the trade's dependence on wild collection through sustainable farming methods of livestock (Rinkevich, 2021). However, notwithstanding active coral reef restoration is a growing practice is not enough at preventing a decline in coral coverage in the next several hundred years (DeFilippo *et al*., 2022).

A top priority for reducing the negative consequences of wild collecting for aquarium species could be the activity of rearing organisms and, specifically, aquaculture of ornamental species (Calado *et al*., 2017). Up to now sabellids, especially belonging to the genus *Sabellastarte*, collected in tropical areas, were imported as a byproduct together with fish. However, there is still no reliable data on the amount of ornamental polychaetes collected every year from coral reefs, as well as studies especially focused on the ornamental polychaete market. Moreover, the farming of polychaetes can be coupled with bioremediation activities. This method has been experimented in the "REMEDIA Life" (Remediation of Marine Environment and Development of Innovative Aquaculture) European project, in which an innovative Integrated Multi-Trophic Aquaculture (IMTA) system has used a new set of filter-feeding organisms, polychaetes, sponges and algae characterized by a high bioremediation performance (Giangrande *et al*., 2020). From a biological perspective, IMTAs are polyculture systems that can combine fish farming with the cultivation of suspension species as organic extractive species and algae as inorganic extractive species. The goal of IMTA is to create a balanced system for environmental and economic sustainability (Barrington *et al.*, 2009; Chopin *et al.*, 2012). The main outcome of this approach is that polychaetes can be used as fish feed, fishing baits and ornamental organisms in the marine aquarium. In such a system, the waste coming from fish production can be converted into valuable by-products promoting circular economy and providing dual benefits: on the one side, reducing the environmental impacts of farm waste and, on the other, increasing profits and decreasing economic risks through product diversification (Barrington *et al.*, 2009). However, current integrated strategies primarily concentrate on species with a known target market, like edible filter feeders. Therefore, research on other powerful extractive organisms with valuable biomass is preferred, such as filter-feeding polychaetes, whose biomass can have a variety of applications. From a managerial perspective, polychaetes deriving from the IMTA system – a biomass with any economic value – have the potential to become a competitive newcomer in the market of the marine aquarium.

The present book has the aim to propose a business model based on an innovative IMTA system in the marine aquarium sector which can be considered a form of sustainability-led innovation–that is, an innovation approach where environmental, social, and economic goals are integrated into the core business strategy, with sustainability acting as a driver for solutions that create shared value for ecosystems, communities, and markets (Bocken *et al.*, 2014; Seebode *et al.*, 2012). However, since the variables that determine successful economics strategies are not defined in the literature, the following research questions are proposed:

RQ1: Which actors, factors, and strategies are required to implement sustainability-led innovations?

RQ2: How can these actors, factors, and strategies be combined in a framework that can aid in implementing a sustainable business model?

Through a combination of methodological approaches and theoretical perspectives, this book develops a framework for understanding and implementing sustainability-led innovations (Figure 1) within the marine aquaculture sector. The work unfolds progressively, following a coherent sequence that integrates conceptual elaboration and empirical application. Firstly, a thorough review of the literature on sustainability-led innovation was undertaken, which enabled the identification of the main conceptual building blocks that support the emergence of radical and systemic innovation pathways. This phase laid the foundation for understanding how environmental, economic, and social goals can be integrated into innovation processes that go beyond compliance or efficiency improvements, aiming instead at the reconfiguration of business models and value creation mechanisms. Secondly, these building blocks were further examined to understand how they operate in practice. Attention was given to the underlying forms of capital–natural, built, human, and socio-cultural–and to the conditions that allow their interaction in supporting the transition toward systems-oriented innovations. This reflection led to the construction of a conceptual framework that links resources, capabilities, and institutional dynamics with the potential for sustainability transformation. Thirdly, the framework was applied to a real-world context through an in-depth case study of an Integrated Multi-Trophic Aquaculture (IMTA) system. This empirical exploration made it possible to observe how sustainability-led innovations take shape in practice, revealing the ecological synergies, circular economy principles, and market opportunities that arise when production systems are reimagined through an integrated and regenerative logic. Fourthly, the insights derived from this case allowed for the identification of the specific elements that characterize a sustainability-oriented business model in the aquaculture sector.

Fifthly, the insights gained from the case study were used to delineate the core components of a sustainability-oriented business model tailored to the IMTA approach. This model emphasizes the strategic role of novel extractive species, the integration of ecosystem services into value creation processes, and the potential for diversifying outputs and markets. It also considers the organizational and managerial adaptations needed to embed sustainability within production systems.

Sixthly, the broader implications of implementing such innovations were examined, focusing on the structural barriers and enabling conditions that affect their diffusion. Key issues include regulatory complexity, limited stakeholder engagement, and the need for supportive policy and financial instruments. At the same time, the analysis highlights opportunities linked to institutional coordination, market incentives, and the valorization of ecosystem services.

Finally, the book concludes by synthesizing the main theoretical and empirical contributions, reflecting on the transformative potential of sustainability-led innovations in aquaculture. It outlines future directions for research and practice, stressing the importance of integrated, adaptive, and systemic approaches to support resilient and inclusive marine production models.

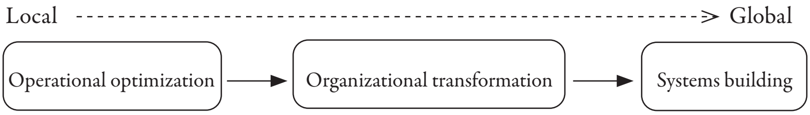

Figure 1: Conceptual framework of sustainability-led innovation

Chapter 2

Sustainabilty Led-Innovations

Luigi Piper, Maria Irene Prete, Federico Mertoli

2.1. Framework for Sustainability-Led Innovations in Business Models

Sustainable innovations can be considered a subcategory of radically new or systemic innovations (Boons *et al*., 2013). According to their perceived degree of novelty, there is a distinction between *incremental* (do better) and *radical* (do different) *innovations*. An *incremental innovation* can be defined as an extension of current knowledge by proposing refinements or improvements of well-known offers that develop in significant increased value for customers (Banbury & Mitchell, 1995). A *radical innovation* defines a discontinuity within the industry and advances by an order of magnitude the technological state-of-art which characterizes an industry (Chandy & Tellis, 2000). This distinction could take place in different ways, specifically, as *product or service innovation* – modifications in the things (products/services) that a company offers; process innovation – changes in the ways in which they are generated and delivered; *position innovation* – modifications in the context in which the products/services are launched; and, finally, *paradigm innovation* – changes in the underlying mental models that frame what the organization does.

Among the various trajectories of innovation, sustainability-led innovation can be defined as a process of developing and implementing innovations that explicitly aim to generate environmental, social, and economic value in an integrated and balanced manner (Bocken *et al*., 2014; Seebode *et al*., 2012). It represents a distinctive and increasingly relevant approach, characterized by the integration of sustainability objectives into the innovation process. Rather than being treated as a constraint, sustainability has increasingly been positioned as a core strategic driver capable of reshaping not only products and services, but also the organizational purpose and role within society (Boons *et al.*, 2013). This shift reflects a transition from short-term efficiency logics toward long-term value creation for a wide range of stakeholders, including the natural environment and local communities (Bocken *et al.*, 2014; Cortez *et al.*, 2022).

Sustainability-led innovation may take the form of incremental improvements–such as reducing emissions, optimizing resource use, or improving energy efficiency–or of more radical transformations, such as the adoption of circular economy principles or the reconfiguration of socio-technical systems (Boons *et al.*, 2013; Bocken *et al.*, 2014). These trajectories often unfold gradually: companies may begin by pursuing compliance and efficiency goals, but as sustainability becomes more embedded in their strategies, they increasingly move toward business model transformation and, in more advanced cases, toward systemic change involving partnerships and collective action (Seebode *et al.*, 2012).

Recent contributions further emphasize this systemic orientation. Mora Cortez *et al.* (2022) show how sustainability-led innovation can serve as a powerful mechanism for revitalizing entire business ecosystems, especially in contexts where legitimacy and trust have been eroded. In such settings, sustainability becomes not only a guiding objective but also a shared narrative through which firms, institutions, and communities collectively redefine their roles and co-create new forms of value.

According to Massa *et al.* (2017), a *business model* is the design of an organization and how that organization functions in order to achieve its goals, such as profitability, growth, and social impact. Specifically, a *sustainable business model* (SBM) incorporates "a triple bottom line approach and considers a wide range of stakeholder interests, including environment and society" (Bocken *et al.*, 2014, p.42). In this perspective, a framework for sustainability-led innovations designs a business model based on the three interconnected elements: economic, environmental, and social. Specifically, such a sustainable business model allows companies: 1) to generate important economic value and high financial performance; 2) to be aware of the consequences of specific actions on the natural environment; and 3) feel a concern of social necessities about people' and communities' health, well-being, education, and employment.

Companies and business models characterized by sustainability-led innovations could experience three different stages. In Stage 1, *Operational optimization*, organizations continue to produce the same products or services but start to reduce harmful emissions or environmental pollution by introducing incremental innovations. In Stage 2, *Organizational transformation*, companies renovate or change their traditional line of production by launching radical innovations. In Stage 3, *Systems building*, organizations initiate the creation of an interlinked ecosystem among new business partners and operate as part of a new entity directed to improve life and health in a better society (Network for Business Sustainability, 2012).

2.1.1. Operational optimization

Operational optimization, defined as the "compliance with regulations or optimized performance through increased efficiency" (Network for Business Sustainability, 2012, p. 8), characterizes a stage in which the company acts as an optimizer. Companies are focused on "doing the same things better" or "to do less harm". They do not essentially modify their business model, but they are able to decidedly decrease their environmental and social damage. By means of incremental innovations, organizations use new technologies and internal resources to deal with a specific problem at a time with the purpose to obtain company-centric innovations, characterized by a reduction of costs or maximization of profits. Some examples of this stage of sustainability-led innovations are the use of reduced packaging, pollution controls, energy-efficient lighting, use of renewable energy, and reduced paper consumption.

2.1.2. Organizational transformation

Organizational transformation, described as "the creation of disruptive new products and services by viewing sustainability as a market opportunity" (Network for Business Sustainability, 2012, p. 9) typifies a phase in which the organization acts as a managerial transformer. Firms are directed to "doing good by doing new things" and, therefore, have the purpose to enter new markets by introducing innovative and sustainable products and services or to use new and environmentally-friendly business models. By using radical innovations, they focus on generating value by technological and sociotechnical improvements designed to benefit individuals by enhancing their quality of life, reducing poverty or the consumption of natural resources. Organizational transformers are still focused on their internal assets and value chains; however, they cooperate directly with external stakeholders and collaborators. Some examples of this stage of sustainability-led innovations include disruptive new products that modify consumption behaviors or help people, replacing products with services, replacing physical services with electronic services, and services with social benefits.

2.1.3. Systems building

Systems building, outlined as "the intimate, interdependent collaborations between many disparate organizations that create positive impacts on people and the planet" (Network for Business Sustainability, 2012, p. 10) describes a stage in which the firm acts as a creator of a new system. Companies realize that a "societal change" and a profound modification in mentality are needed to find coevolving and sustainable solutions in which they are "doing good by doing new things with others". Therefore, they necessitate to go beyond the limits of a single organization and to embrace an original economic paradigm in which each unit jointly cooperates and interacts to develop a sustainable collective system (Table 1).

Some examples of this phase of sustainability-led innovations comprise industrial symbiosis, the process by which discards or by-products of a company or productive process turn into another's necessary resources. Many different organizations collaborate to develop to a "circular economy" where one's organization discarded resources becomes and to a "performance economy". Performance economy focuses on solutions rather than on products, and is based on sufficiency, that is not on the simple reuse of discards obtained during the production process but also on waste prevention (Stahel, 2016).

Table 1: A framework for sustainability-led innovations in the phases of Operational optimization, Organizational transformation, and Systems building.

Phase	*Operational optimization*	*Organizational transformation*	*Systems building*
Description	Observance of regulations or optimized performance through improved efficiency	Creation of disruptive and sustainable products/services	Collaboration between firms and institutions to create net positive impact on the environment and society
Properties	Use of new technologies and internal resources to reduce harm Reduction of costs or maximization of profits	New business models designed to launch sustainable products in different markets	Unconventional economic paradigms Sustainable business models Creation of sustainable systems beyond the limits of a single firm in dissimilar sectors
Examples	Pollution controls, renewable energy, reduced packaging	New products or services that modify consumption behaviors Replacing products with services	Industrial symbiosis Circular economy-based companies
Innovation outcome	Reduction of environmental and social harm	Creation of shared values	Realization of net positive impact on society and the environment
Innovations' relationship to the company	Company-centric innovations Incremental innovations obtained without change of the business models	Sociotechnical and technological innovations Disruptive innovations	External and cross-sectoral collaborations directed to societal change

2.2. The implementation of sustainability-led innovations in the phase of Systems building

To consider a sustainable-led innovation in the phase of Systems building it is possible to take an ecosystem services perspective. Ecosystem services (ES) – sometimes called "environmental services" or "ecological services"– can be defined as the ecological characteristics, functions, or processes that directly or indirectly promote people's wellbeing: they represent the benefits that individuals obtain from operating ecosystems (Piper *et al.*, 2021).

The ecosystems that offer the services characterize the *natural capital*, which outlines a stock that generates a flow of services over time (Costanza & Daly, 1992).

Natural capital includes the necessary natural resources endowments (for example, raw materials) ecosystem structure, functions, processes, and biodiversity.

Sustainable-led innovations in the phase of Systems building require that natural capital interrelates with built or manufactured capital, human capital, and socio-cultural capital (Costanza *et al.*, 2018).

Built or manufactured capital encompasses the fixed assets – material objects, systems, infrastructure, and processes - which contribute to the production process.

Human capital includes the management of human resources. Finally, *socio-cultural capital* includes the resources and assets that are achieved by being a part of a network of social relationships and that foster social mobility beyond economic wealth.

For sustainable-led innovations the transition to the stage of Systems building is not always assumed as it entails several different factors.

Starting from these forms of capital it is possible to identify the building blocks and the conditioning factors that need to be analyzed when formulating and evaluating strategies to enter in the phase of Systems building for sustainable-led innovations (Table 2).

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