Guide for implementing **ecological intensification of aquaculture systems**



This guide was developed in the framework of the multidisciplinary research project PISCEnLIT financed by the French National Research Agency (ANR, SYSTERRA program). The objective was to identify **pathways of ecological intensification of aquaculture** from diverse case studies.

This guide is the result of a **co-construction** bringing together researchers from diverse disciplines of social sciences and life sciences, as well as representatives of institutions and producer organizations in the aquaculture domain, in France and partner countries (Brazil, Indonesia).

It aims to propose an approach, tools, and recommendations for facilitating the ecological intensification of aquaculturel systems by implementing technical, organizational, and institutional innovations. It offers an operational perspective that simultaneously recognizes scientific knowledge and results observed in the study sites of the PISCEnLIT project. **The objective is not to propose a pre-existing model for implementing ecological intensification but to identify a variety of possible pathways** and describe driving factors, mainly environmental and technico-economic, but also those related to questions of coordination and governance, so as to promote social adoption of these innovations.

Besides the innovative character of the concept of ecological intensification, the originality of the approach focuses on the scales at which the intensification is studied: farm and territory. Indeed, our approach concerns not only the production of fish or aquatic products but all of the services rendered by ecosystems associated with aquaculture.

This guide is addressed to **a wide public:** researchers and students, but also managers of territories and aquaculture industries, such as representatives of producer organizations and agents of regional governments or land-planning organizations, who at different scales and in different contexts are concerned by aquaculture-production industries and policies of organization and conservation in the territories where these industries are located.

This guide is not meant to be read in linear fashion. **Each part was designed to be addressed independently**, and readers can thus go directly to the information desired. To facilitate reading and understanding of the sometimes complex scientific terminology, **sidebars** detail methodological or technical aspects or provide examples.

Happy reading …

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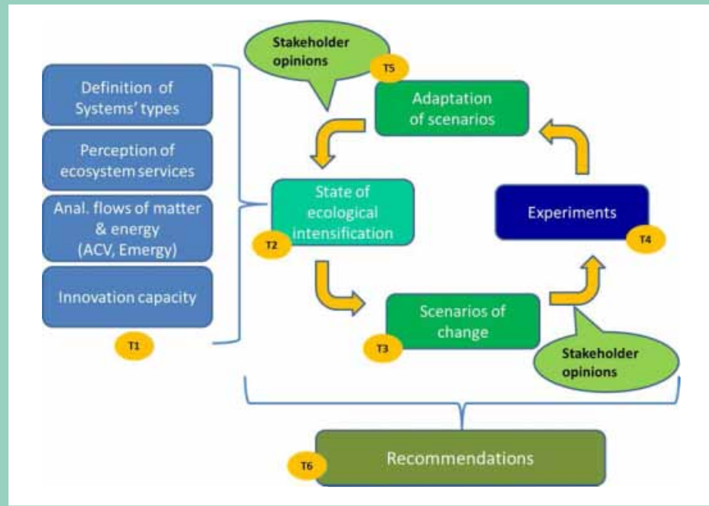
Sidebar 1: The PISCEnLIT project (www.piscenlit.org)

The PISCEnLIT project (PISCiculture EcoLogiquement InTensive) is a research project financed by the ANR (French National Research Agency) in the framework of the SYSTERRA program regrouping partners from the Southern Hemisphere via collaboration managed by the AIRD (Inter-Institutional Research Development Agency). In a global context of stagnation of fishery production, high demand for aquaculture products, and increasing attention paid to sustainability issues, this project falls within the general issue of ecological intensification and aims for better insertion in the territories by developing an ecosystem approach. It addresses these questions according to the Millennium Ecosystem Assessment with an interdisciplinary approach (technical, biological, social, environmental, economic) on four sites chosen to cover a diversity of aquaculture systems and ecosystems. The aquaculture systems studied include a diversity of contexts from developed countries (France: the regions of Lorraine, Brenne, and Normandy) and from Southern Hemisphere countries (Brazil: Alto Vale do Itajaï and the region of Chapéco, Santa Catarina state; Indonesia: region of Jambi, Sumatra). It also includes different types of aquaculture: production-oriented (extensive polyculture systems with few inputs) and transformation-oriented (monocultures, with inputs of feed from outside the farm, open systems, and recirculating systems).

The aim of the project is to define the conditions for applying ecological intensification of aquatic ecosystems. Analysis of the potential for ecological intensification of aquatic ecosystems is organized around life cycle assessment (LCA) and Emergy analysis of the diverse systems as well as assessment of ecosystem services rendered by these systems. The project is composed of 6 tasks. The first aims to develop the ecosystem approach by designing methods to inventory the perception of ecosystem services, the LCA, and the Emergy analysis. In task 2, these results are used to perform an assessment (specific and comparative) of the sites and to develop a simple tool to identify the level of ecological intensification. Task 3 consists of developing scenarios of ecological intensification that combine the specific objectives of ecological intensification as well as a variety of technical and organizational hypotheses for putting them into practice. A few specific actions are the focus of experiments in task 4, in which tests at the pilot-farm scale are performed to supply a basis to evaluate the feasibility of the innovations proposed (task 5) and to make recommendations (task 6).

The team is composed of researchers from INRA (Institut National de la Recherche Agronomique), the Universities of Montpellier and Lorraine, the IRD (Institut de Recherche pour le Développement), CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer), EPAGRI (*Empresa de Pesquisa Agropecuária e Extensão Rural* de Santa Catarina, Brazil), AMAFRAD (*Agency for Marine and Fisheries Research and Development*, Indonesia), DGA (*Directorate General of Aquaculture*, Indonesia), and development partners such as ITAVI (Institut Technique de l'AVIculture, France).



This project follows the EVAD (Evaluation de la Durabilité des systèmes aquacoles) project funded by the ANR program Agriculture and Sustainable Development Durable (Rey-Valette *et al.* 2008).

http://www6.inra.fr/coordination_piscicole/Groupes-de-travail/Systeme-d-elevage/EVAD

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INTRODUCTION: ISSUES AND CHALLENGES OF ECOLOGICAL INTENSIFICATION OF AQUACULTURE SYSTEMS

Aquaculture in the world, its issues and constraints

The increase in the human population of the planet (9 billion around 2050) places heavy constraints on food systems, which leads to a search for ways to strengthen productivity and decrease waste (Foresight, 2011). The forms of industrial intensification put in place since the 1930s have shown their limits. Besides their impacts in terms of resource use and pollution, the desired increase in yields seems to have reached a plateau (Griffon, 2013a). Attempting to respond to increased demand with the same production methods would strengthen land-use competition and intensify recourse to inputs at the expense of conservation of biodiversity and the services rendered by agro-ecosystems. Consideration of sustainable development thus leads to rethinking production systems while accounting for their ecological and social interactions, which implies transforming not only methods of production but also of consumption (Esnouf *et al.*, 2011).

Aquaculture, an activity both traditional and new depending on the species and production system, does not escape this observation and these issues. In fact, **the past few decades have been characterized by a rationale of intensification of aquaculture production systems.** Except in China, production volume from aquaculture has long remained marginal. From the 1970s, substantial research efforts led to rapid development from the mid-1980s. This resulted both from increased productivity of fish farms and increased numbers of fish farmers, which passed from 3.8 mission in 1990 to 16.6 million in 2010 (97% of whom in Asia (FAO, 2012a)). From 1961-2006, average consumption of aquatic products in the world passed from 25 g to 45 g per person per day, of which 47% came from aquaculture in 2006. Today, aquaculture represents half of the production of aquatic resources destined for human consumption (115 Mt), and faced with stagnating fish catches, it is often presented as the solution to the increased demand for edible protein of aquatic origin (FAO, 2012a; Sidebar 2).

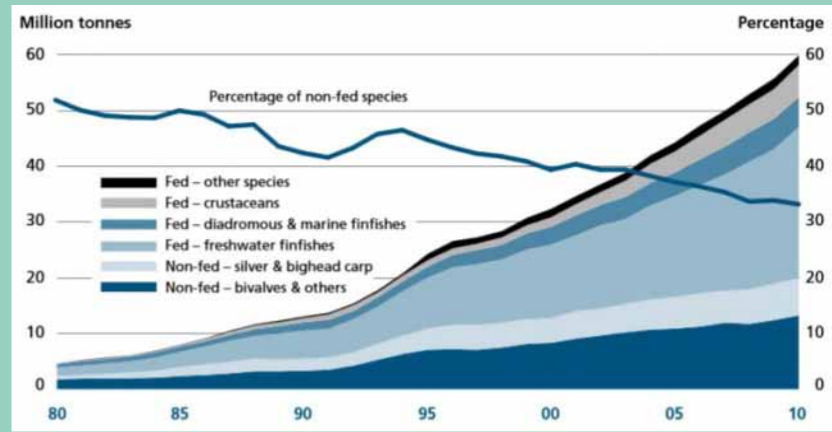
This intensification of aquaculture has often occurred without considering the quality of the environment and/or social relationships. The most striking examples include the following:

- development of industrial shrimp production in Asia, which has led to the disappearance of vast areas of mangroves, to the detriment of biodiversity and increasing the vulnerability of coastal zones to climatic events (Naylor *et al.*, 2000)
- intensive aquaculture near the Japanese or Chinese coasts, which contributes to the appearance of "red tides", fatal to most native species
- exceeding the carrying capacity of local environments due to intensive fish farms in floating cages, as in crater lakes in the Philippines, or accumulating organic waste due to aquaculture activity forced the activity to cease
- excessive use of fishing resources to produce feed is also regularly mentioned (Naylor *et al.*, 2000; Tacon *et al.*, 2010)

Nonetheless, aquaculture systems, faced with the challenge of sustainable development, change. This change results from both normative orders from regulatory systems, such as the Water Framework Directive in Europe and more spontaneous initiatives by the aquaculture sector, which may be motivated by certification programs or an increased desire for integration within territories. Thus, several references in favor of sustainable aquaculture have been developed in France (Black and Wilson, 2008; Rey-Valette *et al.*, 2008; FOESA, 2010; CIPA/ITAVI 2011; Mathé and Rey-Valette, 2011; Blancheton *et al.*, 2012; AquaInnova (http://www.eatip.eu)). This change in practices is strengthened by the consideration of ecosystem services by the *Millennium Ecosystem Assessment* (MEA, 2005) and the *Economics of Ecosystems & Biodiversity* initiative (TEEB, 2010). Even though little adopted by the aquaculture sector (Soto *et al.*, 2008; FAO, 2010; Tacon *et al.*, 2010) compared to forest ecosystems (FAO, 2007), this framework represents an opportunity to implement ecological intensification of aquaculture ecosystems at the territorial scale.

In this way, the social utility of aquaculture is reinforced with the recognition of certain ecosystem services, particularly its role as a sentinel of water quality and its contribution to territorial organization and use of wetlands (Soto *et al.*, 2008; Tanguy *et al.*, 2008).

Sidebar 2: Trends in world aquaculture production



Source: FAO, 2012a

Change in aquaculture production from 1980-2010 by type of production

With 60 million tons in 2010 (FAO, 2012a), world production of aquaculture products (besides aquatic plants) surpassed estimates made for 2020. This increase mainly comes from Asia (in particular China, with 60% of the volume of world production), which intensified its freshwater production systems, especially by introducing formulated feeds into traditional production systems. Other types of production have also increased massively. This is the case for Atlantic salmon (*Salmo salar*) in Europe (Norway, UK), North America (Canada), and in the Southern Hemisphere (Chile, Argentina). This is also the case for panga (*Pangasianodon hypophthalmus*) in Vietnam, whose production has increased in 20 years from a few hundred tons to 1,140,000 tons (Kluts *et al.*, 2012). Rapid development of aquaculture at the global scale hides great differences between geographic zones (low levels in Africa, stagnation in southern Europe).

Terminology about the concept of intensification

Despite the existence of a continuum of systems as a function of inputs and technologies, **it is common to distinguish aquaculture production systems as a function of the input of feed resources to the fish farm.** In this way, the oldest practices fall under "extensive" (or "semi-extensive") aquaculture,

still called "production" aquaculture, are well-developed in Asia (e.g., carp ponds). They are fish-production systems with a short feed chain and the possibility to force the trophic chain with fertilizer inputs. They are often complex and robust polyculture systems whose productivity depends greatly on the nature of inputs, the species assemblage, and knowledge of physical factors. The impact of waste is low because potentially "eutrophying" nutrients are recycled in the pond and in neighboring agricultural production. In contrast to this form of aquaculture, one finds **intensive or "processing" aquaculture**. In this case, nutrients are input via distribution of compound feeds, and water is only a physical support (Billard, 1980). It is thus necessary to manage the emissions caused by the production, either by diluting waste (sea cages, open-circuit production) or by treating them or completely recycling the water (recirculated water circuit).

In this guide, we recognize the possibilities for ecological intensification by considering several examples of aquaculture systems, chosen so as to cover the diversity of system types, which also influence the diversity of services rendered by aquaculture.

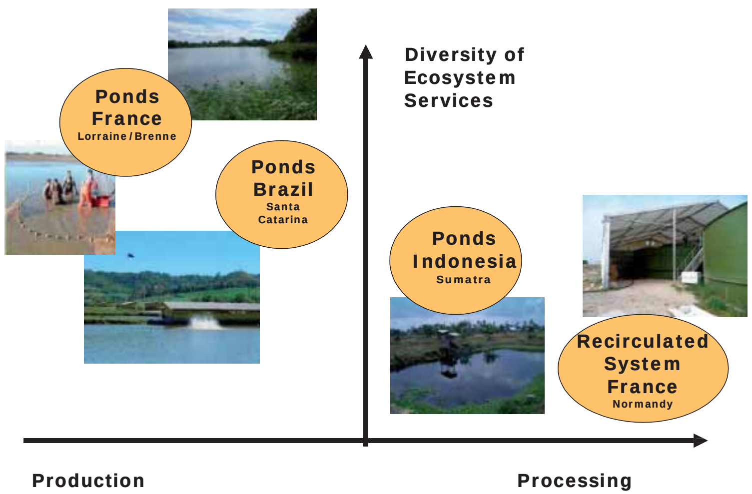
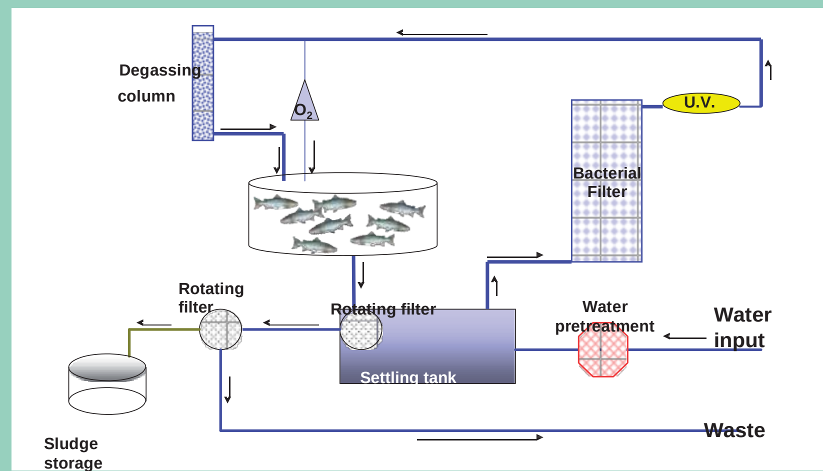


Figure 1: Presentation of fish production systems studied in the PISCEnLIT project according to their link to feed resources and the diversity of services rendered.

Sidebar 3: Principles of systems in recirculated circuits

The recirculating production system regulates water quality water and decreases water consumption (by a factor of 10-100 depending on the technology used) by reusing water from the production tank after treatment in an external loop. In a production tank, the fish consume oxygen and produce CO_2, ammonia, and other metabolic products (factors limiting growth and welfare). As in open system, oxygen can be carried in the incoming water or in the production tank by an oxygenation system (e.g., oxygenation cone, air lift). In contrast, CO_2 and ammonia must be extracted or transformed by an **external treatment loop** (e.g., degassing, nitrification, denitrification). The degree of closure may vary as a function of species or choice of physico-chemical processes (e.g., mechanical filtering, liquid/gas exchange, pH and temperature monitoring) and biological processes (e.g., aerobic and anaerobic biofiltration). It also influences the throughput and concentration of waste, which can be **treated and used** in a second loop (e.g., lagoons or marshland treatment), which **reduces the activity's environmental impact**. The water and energy used by these systems are thus the two main variables and resources that allow for ecological intensification within the production system.



Sidebar 4: The concept of productivity in economics

The concept of productivity in economics corresponds to the relation between the volume of production and the means of production used to obtain it. It measures the efficiency of production processes and their organization. It is a complex concept used to measure and interpret based on the interrelations between means of production and processes, a production factor that can be used for several purposes. Because of this complexity, it is often measured for one production factor independently, for example work or capital productivity (which is called “partial productivity”). It is the combination of all factors that is relatively effective. However, evaluating overall productivity is hindered by the construction of an overall index that combines the production factors used and its realization to consider the technical progress incorporated. The source of productivity gains is not easy to identify. The classic Schumpeterian vision (Schumpeter, 1999) distinguishes five sources of productivity linked to innovation: production of a new good, a new production method, opening of a new market, a new source of raw material, and a new structure of production.

Sidebar 5: The concept of productivity in ecology

Productivity in ecology corresponds to production per unit of biomass (the cumulative mass of organisms occupying the same space (Pourriot and Meybeck, 1995)). Production expresses the formation of tissue per unit of time (cumulative mass of organisms occupying the same space (Lucas, 1993; Jobling, 1994). Primary production refers to organisms that can synthesize their own matter from mineral elements and energy from light. Secondary production concerns consumers of plants, animals, or detritus; their energy thus comes directly or indirectly from primary producers. The increase in mass of farm-raised fish is related to the production (kg/ha/year). The yield or efficiency of the farm is the ratio of consumption (by an herbivore or carnivore) to production of the resource exploited (plants or prey, respectively) (Lucas, 1993). The yield or ecological efficiency is the ratio of production of two successive trophic (ecological) levels (plants and their consumers, the herbivores). Biodiversity helps to increase productivity according to two mechanisms. The increase in species richness (the number of species) increases the probability of having (1) higher-performing species and (2) species that use complementary resources (Bouzillé, 2007).

Sidebar 6: The concept of farm effectiveness

The effectiveness of an aquaculture farm can be studied from four viewpoints:

- Technical effectiveness, which represents a farmer’s ability to produce a maximum quantity of product for a given quantity of inputs
- Economic effectiveness, which is measured as the relation between results obtained and previously-fixed objectives (e.g., production levels, sales, or gross revenue)
- Scale effectiveness, which focuses on the relation between farm size and productivity of production processes
- Allocative efficiency, which considers the farmer’s ability to choose optimal input quantities and production levels as a function of the price of production factors and product sales prices

Sidebar 7: The concept of efficiency

Efficiency is an indicator of performance used to assess systems, projects, and policies. It can measure waste or optimal resource use (e.g., investments, time, work). This indicator relates the results obtained to the resources or means used. Improving efficiency thus occurs by having better results for less effort; that is, by increasing results with constant means or decreasing the means used for the same results. The best-known efficiency indicators are productivity, agricultural yield, and energy efficiency.

Sidebar 8: The concept of performance

The concept of performance refers to measures formulated by indicators for business management or project or policy assessment that consider their consistency, efficiency, effectiveness, and relevance. It is a quantitative indicator that describes the optimal potential of a production system, farm, project, or policy, with the aim of improving their management. This improvement can be measured either in relation to an objective or norm (e.g., profitability threshold) or in relation to a previous period. This measure, qui once allowed one to verify whether objectives had been attained, now aims to anticipate downward slides. Another change in the concept of performance is the passing from monocriterion performance, essentially focused on costs, to a multicriteria concept that includes new variables such as quality, schedules, and innovation, but also social and environmental impacts in general.

CHAPTER 1 . WHAT IS ECOLOGICAL INTENSIFICATION?

In this chapter, we will try to propose a viewpoint the concept of ecological intensification. We will see, in order:

(1) the definition such as it is proposed in agriculture and its link with agroecology (§ 11)

(2) the interest in considering ecosystem services (§ 12)

(3) adaptation of the concept of ecosystem services to the field of aquaculture (§ 13)

11. DEFINITION OF THE CONCEPT OF ECOLOGICAL INTENSIFICATION AND EXAMPLES IN AGRICULTURE

The expression "ecological intensive agriculture" has spread in France since the "Grenelle Environnement" in 2007. It corresponds to a movement of agronomy and agricultural practices inspired by agroecology and conservation agriculture.

Before detailing the potential of ecological intensification for aquaculture, the principles of agroecology from which it comes will first be described and illustrated by a few examples from agriculture.

111. PRINCIPLES FROM AGROECOLOGY

A) Definition(s)

Agroecology comes from reflections of both scientists and producers. It aims to apply ecological knowledge to design and manage sustainable food production systems (Gliessman, 1998). The strength of this movement is that it is composed of three interacting components that strengthen each other and whose level of development depends on the country[1]:

- **agroecology as a new scientific discipline.** Its rise dates to the 1990s (Altieri, 1995; 1999), while the fundamental work is due to German zoologists (Friederichs, 1930) and an American plant physiologist (Hanson, 1939). As a discipline, it can be defined as "**the study of interactions between plants, animals, humans, and the environment within an agricultural system**" (Wezel *et al.,* 2009)[2].

  Today, two research axes can be distinguished: "hard agroecology", which studies flows and interactions (matter, biology, economy) within an agroecosystem, and "soft agroecology", which studies interactions between "hard agroecology" and human activities. This second axis focuses on the role of cultural or academic knowledge, forms of diffusing this knowledge, and experiments that can influence the implementation of technical options proposed by "hard agroecology".

- **agroecology as a set of practices.** It is a matter of proposing alternatives, via farmer practices, to an agriculture that intensively uses chemical inputs and is supported by agrochemicals (Wezel *et al.,* 2009). It has been constructed from a community of farmers organized into networks to optimize and disseminate the innovations produced. **The implementation, even the development, of agroecological principles does not come from a "top-down" process but rather from co-construction by participative approaches that value farmer knowledge and experience.** The role of actor networks should be emphasized in the innovation as well as the importance of processes of social learning (De Schutter, 2010).

- **agroecology as a movement, in the sense of political ideas.** Becoming conscious of the environmental impacts of toxic substances emitted by agriculture was the first step in developing agroecology as a movement, mainly in Latin America and North America in the 1960s. It is now a movement that promotes alternative agriculture via networks of farmers, development agents, and consumers. Its main target is small farmers instead of large agro-industrial farms, judged to be polluting and a source of exclusion of smallholders and the working poor. It supports the image of self-supporting agriculture (Wezel *et al.,* 2009) that can fulfil the needs of the family unit, especially in Brazil. **This movement builds a new baseline, often associated with specific values and lifestyle choices, particularly via ideas of equity and social justice.**

1 Thus, one notes that agroecology in France is particularly understood as a set of agricultural practices, while in Germany it is instead a well-established scientific discipline. In the United States and Brazil, the three components are present, with, nonetheless, a stronger scientific dimension in the United States and stronger development as a "political" movement in Brazil.

2 As with ecological intensification, agroecology can have multiple definitions. Ecological intensification can, for example, encompass approaches such as "eco-agriculture", "persistent agriculture", or "sustainable intensification" (Pervanchon and Blouet, 2002).

Agroecology is an extension of systems approaches. **It has echoes in economics with the development of the bio-economics courant** (Passet, 2010). It is a matter of economics "opening itself to the biosphere, of which it is only one subsystem, and not the integration of the living into strictly economic reasoning"; that is, to "insert economic activities in natural and human ecosystems without altering the functions that give them continuity over time" (Passet, 2010). Two main principles are emphasized: interdependence and circularity, which lead systems to regulate themselves by the complex set of dynamic feedback.

Sidebar 9: Definition of circular economy

One of the starting points for implementing ecological intensification is the practice of internal and external recycling developed in industrial ecology. These practices, performed during production processes, take advantage of waste (or in general, co-products) internally or externally. These developments refer to "cradle-to-cradle" approaches that aim to break with the linear reasoning: extract, produce, consume, throw away. The circular economy fits into this reasoning by proposing to produce differently by integrating ecological requirements at all levels: from design, to production, and up to recycling. Circular economy aims to improve the efficiency with which materials and energy are used. In this model, the energy sources used should be as renewable as possible, while avoiding the use of chemical products. However, the essential link is zero waste. This reasoning is under development in industry, especially with the support of tools such as Life Cycle Assessment and Emergy Analysis. In agriculture, the question of recycling was mainly developed in a rationale of diversification or integration of activities.

B) Principles

The basic principle of agroecology is the conservation and recognition of biodiversity. This principle boils down to the assertion that **the greater the biodiversity, the more the system is productive and resilient in the face of climate variations, pest infestation, or diseases.** Altieri (2002), the author of the most frequently cited reference, proposes five principles to guide agroecology of cropping systems:

1) Recycle biomass and balance nutrient and energy flows
2) Protect soil quality by improving organic matter and biological activity
3) Minimize losses of solar energy, water, air, and nutrients by creating microclimates, recuperating water, and covering soil
4) Strengthen genetic and species diversity within agroecosystems in time and space, in particular by integrating cropping and animal-production systems
5) Strengthen beneficial biological interactions and synergies between components of agrosystem biodiversity by supporting key ecological processes and services. This principle emphasizes interactions and productivity at the scale of the entire agroecosystem rather than of individual varieties

Besides their environmental dimension, these principles also have a strong equity and social-justice dimension. It is a matter of ensuring food availability for all but also to increase revenues of smallholders. Emphasis is also placed on the use of local knowledge, especially for readapting former practices or benefitting from innovations and experiments implemented by farmers as a function of the context.

C) Conditions and application scales

Transitioning to agroecology can have high costs and require specific help. We mention here a few ideas for the main assistance measures that may be necessary.

One can mention the obvious need to strengthen dissemination of research to farmers but also, depending on the context, to develop installations for storage and collective organizations (e.g., cooperatives, networks), to facilitate access to the market and to credit, and to implement regulation measures for markets, especially to stabilize prices. The integration with ecosystems can strengthen medium-term sustainability of farm that benefit from the natural processes of resilience (if they are not overexploited). However, in the short term, this integration can also generate greater vulnerability to climate variations, which should be guarded against. Finally, the existence of governance structures adapted to different scales should be ensured. Acknowledgement of local knowledge and the existence of objectives of equity and social justice

imply considering the importance of the role of actor networks in the innovation process and knowledge sharing, and implementing participative approaches. The latter aim to promote adaptation of innovation to contexts, but also to strengthen learning, autonomy, the abilities of small holders, especially women, as well as the legitimacy of the these policies (De Schutter, 2010).

Implementing agroecological principles implies many scales. This diversity of scales results especially from the role of the underlying ecological interactions. Due to interactivities with natural processes, production functions become more complex and change scale in such a way as to connect with the function units of the environment (e.g., the watershed, for regulation of water quality and availability). Wezel *et al.* (2009) propose three scales for the study of agroecology: (i) plot or field, (ii) agroecosystem or farm, and (iii) the entire food-production system.

112. APPLICATION OF ECOLOGICAL INTENSIFICATION IN AGRICULTURE: SOME CONCEPTS

A) Principles and examples

Referencing the principles of agroecology, ecological intensification of agriculture (CIRAD, 2007; Chevassus-au-Louis and Griffon, 2008; Griffon, 2010) bases itself on the naturally productive functions of an ecosystem and seeks to optimize them to attain yields comparable to those of conventional agriculture, while reducing the use of chemical inputs and environmental degradation. One benchmark definition is that of CIRAD (2007): ecologically intensive agriculture "**relies on ecological process and functions to combat pests, decrease pollutants, use scarce resources better, and improve ecological services**". Regardless of the definitions, of which there are many, in all cases, knowledge of interactions with the natural environment must be strengthened to identify increases in productivity that can create a combination of ecological and agronomic processes. The concept of "increase in productivity" is meant here in its largest sense. It can be defined as volumes as an increase in yields or decrease in losses. One can also envision increases in productivity as values when newly adopted practices reduce spending or improve use of products. Ecological intensification thus aims to "decrease use of inputs and instead use natural resources and functions, while decreasing negative externalities" (Griffon, 2013a).

Ecological intensification can take many forms, which implies that its contours remain fuzzy and changing. The most common image is replacing chemical inputs with natural processes. One can cite, for example, intercropping to combat pests, mulch-based direct seeding to reduce irrigation, and aerating soil with earthworms instead of tillage. The options are diverse; the economic, sociological, and institutional obstacles are many; and the need for ecological knowledge is great (Griffon, 2013a). The diversity of implementation pathways led Griffon (2013a) to diagram both the diversity of possible entry points and differences with conventional agriculture (Fig. 2). The diagram demonstrates large changes both prior to technical operations, at the level of inputs, and afterwards, for outputs in the wider sense (products, but also externalities generated).

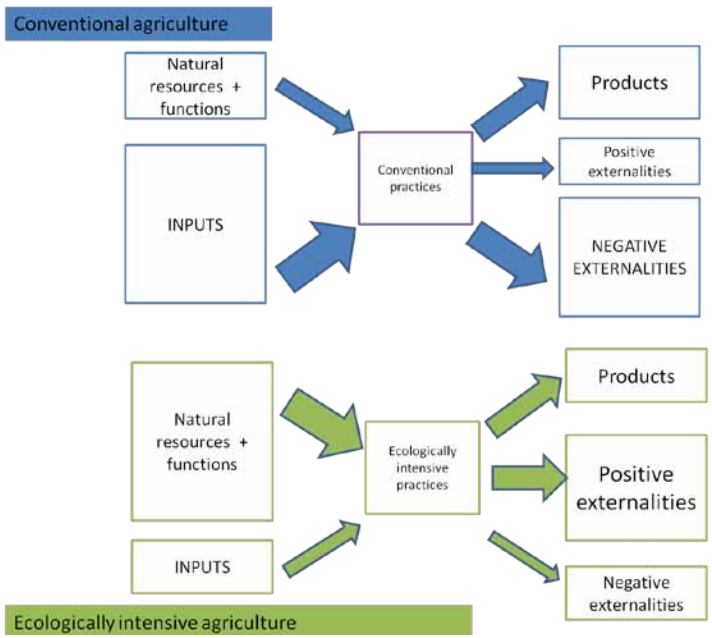


Figure 2: Comparison des conventional and ecologically intensive agricultures (Griffon, 2013a).

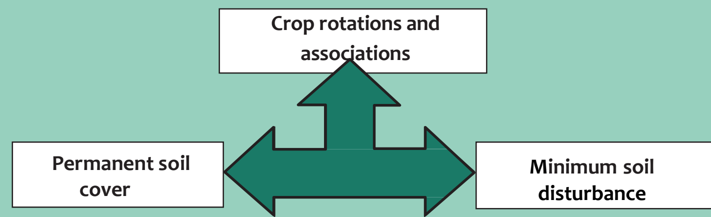
B) A new eco-farmer

The concept of ecological intensification marks a new orientation of agriculture. It breaks with the phase of classic intensification, which manifested itself in agriculture with the passing from peasants to farmers, then

the agricultural entrepreneur. More generally, one notes over time that the hunter-gatherer/predator-prey has become a farmer and a shepherd, then an engineer constructing systems or fashioning the environment for his or her own use. The introduction of sustainable-development objectives has led progressively to rethinking production modes to take into consideration environmental constraints, issues of land planning and landscape conservation, as well as questions about product quality and food security. These changes have thus impacted the definition of the profession of a farmer. At the moment, the agricultural entrepreneur tends to become the eco-farmer with a variety of subtypes: organic, reasoned, sustainable, or conservation farming (Pervanchon and Blouet, 2002).

Sidebar 10: Example of mulch-based direct seeding: no soil tillage, permanent plant cover, wise crop succession

The FAO (2012b) defines conservation agriculture (CA) as "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment". Conservation agriculture is characterized by three interacting principles shown below.



These principles are context-specific. Their combination depends on the zone in which they are applied. Their implementation requires particular skills to set up the crop rotations and associations and manage the permanent cover and minimum soil disturbance depending on the type of soil, the rotations, and the type of crop.

C) *The illusion of simplicity and a return to ancestral practices*

Two complementary pathways to ecological intensification differ from one another depending on whether one relies on resuming former practices or on knowledge from industrial ecology, by integrating significant support from information technology (Melville and Ross, 2010). Depending on the context, different rationales exist: indeed, one speaks more of ecological intensification in less-developed countries but of "greening" of practices in developed countries. **In either case, ecological knowledge must be developed, and the illusion that these practices are simple should be dropped.** On the contrary, besides the complexity of the ecological processes that are used, it appears that ecologically intensive agrosystems are more complex, since they use more species than conventional agriculture does. The consequences are double: innovating within the farm by adopting new practices but also improving the quality of the environment at the regional scale. Also, not only are farm managers and the agricultural word affected but society as well. This second scale transforms the image of the sector for consumers and citizens. It can generate the gift of subsidies or specific types of enhancement when gains from economic productivity are not sufficient.

D) *The place of innovation*

Any adoption of new practices or operations refers to the theory of innovation, which emphasizes not only knowledge of technical procedures but also organizational and institutional innovations. Ecological intensification comes with a strong need for knowledge, especially agronomic and ecological. **It involves specific innovations oriented toward eco-innovations or environmental innovations** (Aggeri, 2000; 2011). These eco-innovations include new ideas, behaviors, products, processes, platforms, or organizations that help respond to the objectives of ecological sustainability (Renning, 2000; Charue-Duboc et Midler, 2011).

Implementing these principles in agriculture in France faces sociological constraints due to the change in representation of the profession that these practices imply (Michel-Guillou, 2006; Fernandez *et al.,* 2009). One consequence is a **change in the skills and status of the farmer, who tends to become or be seen as a co-producer with nature of a service that is no longer only food- or market-related.** These transformations also impact the structure and nature of support systems and professional networks.

The latter, now connected to the internet, act in larger groups, both in scale, often with international links, and in the type of actors, with frequent collaboration with non-farmers (communities, environmental NGOs, etc.). **These new networks create new technical, even social, elites that lead to reorganization of sets of actors** (Fleury *et al.,* 2011). Lemery (2003) alludes to the fabric of a new agriculture by showing increasing reflection by farmers, while Stassart *et al.* (2011) speaks of an agro-ecological transition and mentions, in the spirit of new sociological approaches (Giddens, 1994; Beck, 2003), a reflexive modernization process.

Sidebar 11: Example of sociological constraints to adopting reduced tillage

Any innovation, as a social construct (Akrich *et al.*, 1988a and b), will always, when it is begun, encounter detractors and create defensive reactions for many reasons. For example, adoption of principles of ecologically intensive agriculture faces cultural reluctance by farmers. In fact, leaving crop residues on a field goes against social codes that say that a good farmer should leave a field clean after harvest. Those who do not harvest residues (straw) are not considered "real farmers". To this cultural constraint is added other socio-technical constraints (Goulet, 2013), such as a lack of reference values. Farmers' risk aversion and financial uncertainty (loss of revenue) may also explain, in many cases, the lack of adopting these innovations.

Finally, these new practices work together with the emergence of new values and a "political" movement. It is not only a matter of acquiring new skills from training or experiments, but to take on new values and collectively co-construct a new norm. Certain authors (Lemery, 2010; Goulet, 2012) thus show the importance of the distance between representations of the profession and the technical model of farmers and the new principles and practices that the adoption of ecological intensification involves: the further these principles and practices are from the reference model, the lower the chances that these innovations will be adopted quickly. It is thus useful not to limit oneself to the technical aspects of innovation but to explore the social and organizational dimensions that also play a decisive role. The importance of these social and organizational processes leads to adopting translation approaches between science, agriculture, and society recommended by trends in the sociology of innovation (Callon *et al.*, 2001). Thus, the case of sustainable development or ecological intensification, which assume changes in values or frames of reference, imply specific learning, called "double-loop" learning in management science (Argyris and Schön, 1996).

Sidebar 12: Double-loop learning

Argyris and Schön (1996), in studying organizational change, revealed three types of learning. (1) "Single-loop" learning implies modifications in practices, ways of doing, working, and coordination but no change in the "decision model". (2) When changes involve strategy and objectives at the scale of the activity or nature of the organization (e.g., passing from a private company to a cooperative), that is, they involve a change in values or action models, it is considered "double-loop". (3) Finally, when it is a matter of changing how one learns to learn, the authors speak of "triple-loop" learning.

113. WHAT PATHWAYS FOR APPLYING ECOLOGICAL INTENSIFICATION TO AQUACULTURE?

The transposition to aquaculture can first rely on adapting to animal production the principles of agroecology proposed by Dumont *et al.* (2012). **In animal production systems, these practices lead to producing feed on the farm, preventive healthcare methods rather than curative ones, and use of heritage breeds.** Significant effort also focuses on animal welfare, especially to reduce stress and additive use (growth hormones). More generally, they aim to avoid forcing physiology by getting better use of natural functions. Dumont *et al.* (2012) proposed five principles for animal production systems that can be adapted to aquaculture systems. They represent a certain animal production systems for which no principle of reference has been proposed. These principles are presented next by providing a few examples of possible practices for aquaculture (Table 1).

Table 1: Principles of agroecology for terrestrial and aquatic animal production systems

Principles proposed by Dumont *et al.*(2012) for animal production systems	Examples of possible application to aquaculture systems
P1: Adopt practices that increase animal health	Developing use of techniques of phytotherapy and allelopathy
P2: Decrease inputs from human systems	Integrating aquaculture into terrestrial animal production systems such as pig-fish associations in Brazil
P3: Decrease pollution by optimizing metabolic functioning	Local use of waste from aquaculture systems (sludge, nutrients, etc.) as inputs for agriculture
P4: Increase diversity in animal production systems to strengthen their resilience	Practicing multi-trophic aquaculture, which combines species of complementary trophic levels
P5: Preserve biological diversity of agrosystems by adapting management practices	Maintaining vegetation and reed beds on pond edges, for example to help maintain biodiversity

For example, in Brazil, agroecology principles have been known for nearly 20 years and are applied in the development of a specific model of aquaculture called "*Modelo Alto Vale de Itajai de Pisicultra Integrada*" (MAVIPI (Sidebar no. 14)). Practiced in the state of Santa Catarina, this model is based on two levels of integration: pig production and fishpond, and exploitation of the trophic chain in a carp polyculture (Sidebar no. 13). This system responds to the second, third, and fourth principles of Dumont *et al.* (2012).

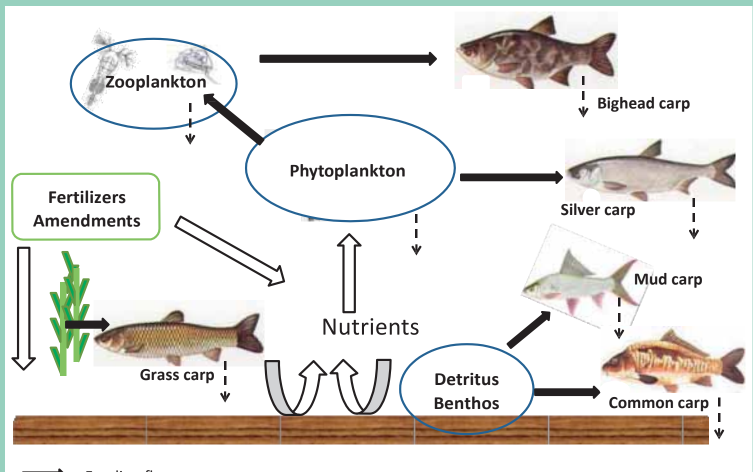
Sidebar 13: Definition and functioning of trophic networks

The trophic network describes feeding relations between individuals belonging to different communities of species in an ecosystem (biocenosis). The large number of taxa consumed by a given species or consuming the same species summarizes the complexity of predator-prey relations. As a consequence, it is preferable to abandon the idea of trophic chain in favor of trophic network, which better accounts for omnivory (Pourriot and Meybeck, 1995). Plants occupy the lowest trophic levels, the highest trophic levels being occupied by tertiary consumers (predators of carnivorous fish, for example). To these predation compartments are added trophic effects, that is, phenomena and behaviors that are modify trophic networks in the absence of consumption. Bioturbation caused by carp is the best example: agitation of the sediments caused by this species makes the water turbid, which negatively impacts submerged plants; in contrast, the suspended nutrients favor phytoplankton production.

In an extensive fish farm, trophic levels are managed in three successive steps:

(1) supporting the trophic network by adding inputs
(2) manipulating the trophic network by orienting colonization by species using production practices
(3) harvesting by extracting products from the system

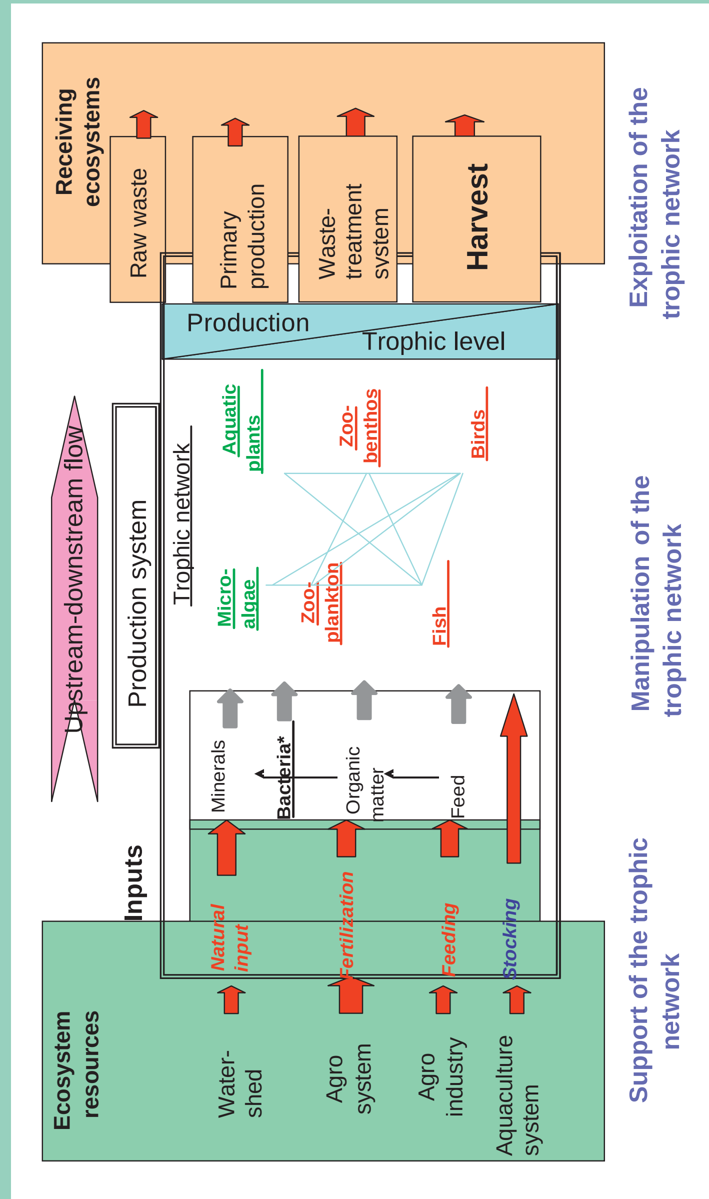
An emblematic example of manipulating the trophic network is polyculture of Chinese carp, in which species have been chosen for their trophic complementarity, which better uses the many ecological compartments of the pond.



Polyculture of Chinese carp

After Milstein (2005)

Continuation of Sidebar 13



Sidebar 14: Presentation of the MAVIPI (*Modelo Alto Vale de Itajai de Pisicultura Integrade*) model

The MAVIPI model was developed in the 1990s in Santa Catarina, a state in southern Brazil. It was developed by scientists at EPAGRI in response to the double constraint of having a system that respects the environment and is productive. It is based on integrating pig production and fishponds according to a ratio of about 80-100 pigs per ha of pond. The pond contains polyculture fish production based on trophic complementarity of different carp species (grass car, bighead carp, silver carp) and a target species, which is common carp or tilapia. This model is a modern version of the ancestral Chinese system. It uses formulated feed when the growth allowed by pig waste is no longer sufficient. Aerators are responsible for homogenizing the water and intensifying gas exchange (oxygenation, elimination of CO_2). This system produces 5-10 t of fish per hectare per year. It is necessary to have two cycles of pig production of 5 months to equal one cycle of fish production of 10 months.

Sidebar 15: Benefits of phytotherapy or use of plant biodiversity for therapeutic aims in aquaculture

Simplification of aquatic ecosystems, such as one observes in intensive aquaculture systems, is accompanied by an increase in the pressure of disease agents an altering of the host-pathogen balance, which often triggers epidemiological or enzootic diseases within a production system (Caruso, 2009). Faced with significant production losses, the fish farmer then can resort to a non-specific therapeutic arsenal for aquatic animals, with mixed results for the stock and a known risk for the consumer and, more widely, a public-health risk. In particular, anti-infection substances, especially antibiotics, represent a persistent threat to public health via potential residues in fish meat, but also via mechanisms of bacterial selection and antibiotic resistance, which can be transmitted to environmental bacteria and possibly pathogens (Serrano, 2005; Sarter *et al.*, 2007). Many countries have thus restricted use of medicine in aquaculture, which has also increased fish farm expenses.

Faced with these difficulties, Asian fish farmers, especially Indonesians, rediscover and adapt traditional therapeutic practices based on plants. Phytotherapy, widely present in Indonesian daily life, is thus used by fish farmers on Java. Recent ethnobotanical surveys (Caruso *et al.,* 2013) highlight wide use of plants and unexpected richness (about 100 plants). Nonetheless, use of these plants varies depending on the experience of the fish farmer, the species of fish raised, and the degree of intensification of production practices. Surveys of traditional fish farmers performed in northern Vietnam also outline the predominant use of plants to decrease mortality in farms. The fish farmers surveyed recognize a diversity of therapeutic actions of plants and sometimes even specific use against bacterial or parasitic diseases. This capacity for observation and judgment is particularly important for identifying potential plants for an effective aquatic pharmacopeia with limited ecological impact. However, this knowledge remains largely empirical, and fish farmers constantly ask scientists for information about the use of plants, their doses, their effects, and their administration methods.

Between tradition and discovery, fish farmers test and adopt the use of plants, often due to word-of-mouth or discussion among colleagues. The role of education and vulgarization of aquaculture in Indonesia should also be highlighted in the diffusion of plant use by fish farmers. Consequently, this adoption and then reasoned use of plants is a development that involves traditional know-how, government organizations, and active participation by research in a request that is sector-specific but also widely social.

12. WHY DEVELOP ECOLOGICAL INTENSIFICATION AT THE SCALE OF ECOSYSTEM SERVICES?

The expected consequences of ecological intensification do not only concern food production (supply service), but influence all ecosystem services (MEA, 2011). In particular, ecological intensification can develop through intensification of regulation or support services, which have direct links with environmental conservation. Certain cultural services, for example landscape maintenance, ecotourism, sensitivity to environmental issues, can also be involved directly, when it concerns a desire to diversity, or indirectly, as an unplanned consequence. **It is a matter of surpassing the production of positive externalities offered by the classic approach of ecological intensification to integrate the fact that development of these services is the fruit of a voluntary action and is sought by the farmers.** The status of farmers or fish farmers is changing. They are becoming co-producers with nature of a service that is no longer food-related and with is not necessarily market-oriented.

Sidebar 16: Reminder of a few definitions

The concept of externality	The concept of amenity
A situation in which the welfare of a person or the results of an activity are affected by another actor or activity with direct market compensation. This compensation must thus become the subject of specific regulations. Among many examples, we can cite diffuse agricultural pollution toward groundwater, which impacts the water quality of consumers or even the activity of a mineral-water company, such as the oft-studied case of Vittel (Brossier *et al.*, 1993). One can distinguish positive or negative externalities.	Attribute of a territory that may be natural or created by humans (most often, cultural heritage) and that is linked and specific to this territory. Amenities thus differentiate territories with and without them. An amenity is always considered as a positive characteristic. One can cite the example of neighborhoods with a sea view, in which the existence of this amenity explains large differences in real-estate prices.

Extending ecological intensification to ecosystem services (MEA, 2005; TEEB, 2010) has the benefit of an operational frame of reference and offers a positive approach to conservation or even restoration[3] of ecosystems. The links established between environmental preservation and social welfare fall within positive scenarios of win-win public policy, in particular for compensation measures provided for zoning operations or agricultural policies.

Sidebar 17: Regulating compensation measures

Concerning the decrease in and regulation of the impact of zoning, infrastructure, and/or exploitation operations of biological resources that damage biological diversity, the French and European Union legislative framework is based on the triplet: "avoid, reduce, compensate". In France the principle of compensation is integrated into French law by the code on the Environment and the law regarding environmental responsibility (Law 2008-757 of 1 August 2008), which aims to transpose European Directive 2004/35/CE. Compensation thus only becomes involved to supplement measures to avoid and reduce impacts and should concern only residual or inevitable damage of the project on biodiversity. It is a matter of performing measures to restore, create, improve, or prevent loss or degradation of a type of ecosystem from the viewpoint of biodiversity, in terms of species composition, habitat structure, and the ecosystem services rendered.

121. TAKING ECOSYSTEM SERVICES INTO ACCOUNT

The *Millennium Ecosystem Assessment* (MEA, 2005[4]) addresses the protection and functioning of ecosystems via the services that they render to society by their contribution to human welfare. One can distinguish four types of services and five types of contribution to welfare (Sidebar no. 18). This framework, which allows a positive approach for protecting the environment, leads to defining ecological intensification not only at the scale of the terrestrial or fish farm but its surrounding ecosystem. It consists of considering the set of ecosystem services that this intensification can influence, as a function of practices, territorial integration of farms, and physical contexts. Subsequently, according to the services, the scales can be wide.

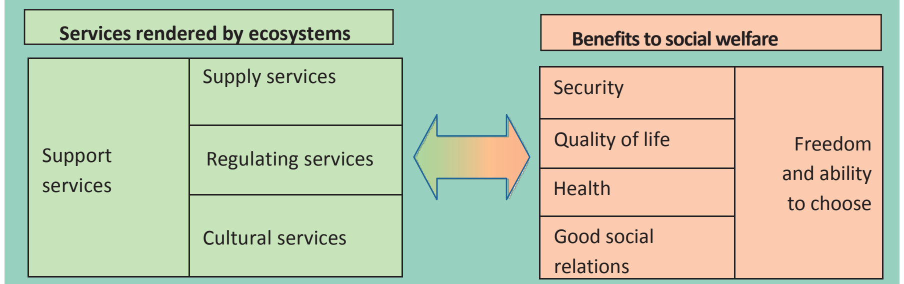
3 For human-created ecosystems, it would consist mostly of maintenance or zoning. Strong controversy exists over the concept of restoration in describing the initial state, especially in situations where ecosystems have been greatly and for a long time managed by humans.

4 It is common to associate this movement to work by the international workgroup assembled by the Secretary General of the United Nations, Kofi Annan, from June 2001 to 2005 in the framework of the Millennium Ecosystem Assessment. The objective was to produce an assessment system adapted to the needs of decision-makers. Nonetheless, many founding works exist, as described by the review of Gomez-Baggethun *et al.* (2010) or the special issue of the journal VertigO (Bonin and Antona, 2012).

For example, maintenance of reed beds around aquaculture ponds, as a wetland (Barnaud and Fustec, 2007), strengthen the support service (nesting, feeding, shelter) for certain birds, and for migrating birds, the consequences of this service must be examined at a spatial scale that can be continental.

Sidebar 18: Principles of the ecosystem approach

The MEA (2005) and TEEB (2008) mark a key step that institutionalized a new framework integrating human activities, biophysical activities, and human welfare. This approach, called "ecosystem", proposes a positive perception ("win-win") of environmental conservation in terms of contribution to human welfare (Chevassus-au-Louis *et al.*, 2009). Criticized by some for its human-centered character, it leads to understanding ecosystem services either as the product of natural capital ("ecological economics" movement), a positive externality (environmental economics), or an activity falling under the service economy (Aznar *et al.*, 2010; Froger *et al.*, 2012).



In common terminology, "ecological services" and "ecosystem services" are often used. One also encounters the wider term "environmental services" (Amigues and Chevassus-au-Louis, 2011).

122. ADAPTING THE CONCEPT OF ECOLOGICAL INTENSIFICATION TO THE SCALE OF ECOSYSTEM SERVICES

The five principles of agroecology (see 111) have effects both on the farm and the farmer, but also on the territory in which the agricultural activity occurs. These two levels can be separated in the sense in which interactions between practices and ecosystem functions are the central point of ecological intensification. Nonetheless, it is possible to distinguish levels of decision and objectives when implementing these practices.

Motivations for farmers may be to seek more autonomy, more efficiency, or greater territorial integration of production systems. These reasons may be related to some degree to changes in values, which may be behind implementation of ecological intensification and/or result from iterative reasoning in which implementation of ecological intensification would first be limited to a few activities, then more broadly considered in terms of integrated territorial management. Consideration of ecosystem services thus introduces functional interactions within ecosystems and a diversity of scales, which are useful to consider at the level of implementing ecological intensification activities. Intra- and inter-territorial environmental solidarity[5] must be strengthened in the spirit of recommendations for maintaining or constructing ecological corridors or green and blue spaces, which aim to preserve biodiversity.

Sidebar 19: Definition and contribution of the concept of ecological solidarity

The concept of ecological solidarity comes from Law no. 2006-436 of 14 April 2006, which reformed national parks. It aims to go beyond the opposition between protected zone (the central zone of a park) and periphery (buffer zone) by replacing it with a more interactive vision of space to ensure better territorial coherence. Likewise, it goes beyond the opposition between remarkable biodiversity and ordinary biodiversity, especially by showing the key role of "ordinary" species in green and blue spaces. "Ecological solidarity is based on the close interdependence between two geographic spaces, whether contiguous or not" (Mathevet *et al.*, 2010). It integrates two concepts: actual ecological solidarity, which considers multi-scale ecological functioning, and action-oriented ecological solidarity, which considers the choice of management methods. **Actual ecological solidarity** considers functioning via many criteria that include spatial organization of the territory and management of flexibility. Six criteria were developed: functioning of large sets or systems, ecological continuity and territorial coherence, complementarity of sites, consideration of species movements as a function of habitat types, population dynamics, and possible responses for adaptation to climate change.
Action-oriented ecological solidarity involves reflecting about conservation of functioning and natural resources within a territorial plan or natural-park charter while considering cultural and landscape heritage and socioeconomic issues and practices. "It emphasizes the common destiny of humans, society, and its environment" (Mathevet *et al.*, 2010).

[5] This concept should be distinguished from questions of imported or exported sustainability, which consider spatial interdependencies and which lead to defining summary indicators such as a territorial footprint or approaches for the life cycle of a product. It is only when the balance between internal and external sustainability is ensured that one can speak of effective sustainability, the other cases leading to sustainability that occurs to the detriment of other territories, for which the concept of "territorial sacrifice" developed by Nijkamp *et al.* (1992 cited by Laganier *et al.*, 2002) can be evoked.

It is important to note that the human-centered character of the MEA (2005) framework implies that the existence of an ecosystem service is determined by the **existence of an effective demand or use**. It may consist of direct or indirect use or recognition of a value (value of choice, legacy, or existence), given that these uses and values are mostly a function of the context. Finally, we emphasize that consideration of ecosystem services does not aim to place economic value on them, even though this is one way to increase diversification of farm or territory revenues. The main objective is to identify the existence of these services but also their level of recognition by studying how actors perceive them to identify the most operational methods and integrate them in an ecological intensification approach.

13. SERVICES RENDERED BY AQUATIC ECOSYSTEMS

131. INVENTORY OF SERVICES

From examples of aquaculture systems studied in the PISCEnLIT project, the objective is to describe the ecosystem services rendered by aquatic ecosystems (Table 2) by adapting the framework of the MEA (2005). It consists of a long generic list, since the range of these services will vary as function of the aquaculture system and territorial context.

Table 2: A few key examples of ecosystem services rendered by fishponds.

Supply services	
Fish production	Fish production for human consumption is the reason for creating aquaculture infrastructure. It may consist of one species or many in polyculture, or even species besides fish (mollusks, crustaceans, aquatic plants).
Freshwater reservoir	The function of water reservoir may be direct or indirect depending on whether the ponds contribute to irrigation or groundwater recharge.
Fiber production	Exploitation of reed beds (thatch) or production of forage from bank maintenance; furnishing of combustible materials from bank vegetation (riparian vegetation).
Fertilizer input	Fishpond sludge allows crop growth when ponds are dry or can be used as fertilizer to produce vegetation on banks or neighboring agricultural production.
Regulating services	
Climate regulation	Fishponds can act as carbon sinks or help regulate local climate (temperature, air humidity).
Hydrological regulation	Fishponds help recharge groundwater and buffer flood events. Acting as reservoirs, they may help contain wildfires.
Regulation of human and animal diseases	Aquaculture can use invasive species from other agrosystems and help regulate their pathogens (e.g., molluscivore cichlids are used to control development of pond snails, a vector of schistosomiasis).
Pollution retention and remediation	Fish ponds purify water by degrading organic matter, trapping heavy metals in sludge, or metabolizing organic pollutants.

Cultural services	
Link with religion, local culture, and traditions	Certain fish species raised in ponds perpetuate local recipes (carp in France or "*pindang patin*"[6] in Indonesia). Establishment of fishponds dates to the Middle Ages in Europe, and fish from ponds are often shown in town coats of arms, a witness of the heritage role of the activity. Annual fishing events are often the focus of traditional celebrations.
Source of inspiration and sentimental value	Monet, in his "Water Lilies" paintings was inspired by the water lilies in his pond at Giverny. Ponds are often a subject of photographs (postcards).
Learning of know-how	In traditional fish-production regions, practices and know-how form part of local heritage and are highlighted in museums (e.g., museum of the ponds of Lindre in Lorraine).
Sensitivity to environmental issues	High biodiversity in zones of fishponds, especially for migrating birds, frequently leads to developing hiking trails and observation sites. Ponds are preferred sites for environmental education and host educational excursions by school groups ("green classes").
Hunting and fishing	Fish ponds offer recreation activities for leisure fishing and organized fishing competitions ("pesque paque" in Brazil or "kolam mancing" in Indonesia). Fry production for restocking supports leisure fishing and watercourses and waterbodies. Fishponds are also preferred places for waterfowl hunting.
Tourism, ecotourism, landscape	Tourist attraction to fishpond zones results from the unique landscapes created by the presence of many ponds (e.g., tourist communication for Benne in France is based on being the "region of a thousand ponds").
Support services (biodiversity maintenance)	
Primary production and support of natural nutrient cycles	Fish ponds are environments that favor production of algae (plankton, epiphytes) and aquatic or semi-aquatic plants and have an auto-purification function that can recycle nutrients.
Zones of refuge, nesting and spawning	Fish ponds and their associated wetlands furnish habitat or refuge zones for many bird, plant, or aquatic species (fish, amphibians, crustaceans, insects, etc.).
Soil maintenance	By retaining water, ponds help decrease soil erosion.

[6] Soup based on panga fish in Indonesian.

132. CONSIDERATION OF PERCEPTIONS TO IDENTIFY THE DEGREE TO WHICH SERVICES ARE RECOGNIZED

Recommendations for consideration of ecosystem services emphasize the prerequisite importance of an identification phase from perceptions. The study of perceptions falls into the field of analysis of social representations, which considers judgments, values, and information to which a social group or individual refers. The study of social representations comes from sociology and psychology and implies qualitative interviews and discourse analysis. Knowledge of perceptions requires suitable survey protocols (Kaplowitz, 2000; Kumar and Kumar, 2008; Quetier *et al.*, 2009), which voluntarily associates closed questions that aim to establish typologies and open questions to analyze spontaneous perceptions. They are commonly used to study preferences of populations and their level of information about public policy.

Sidebar 20: Perceptions and representations of the environment

The study of representations of environmental questions is the base of environmental psychology (Moser, 2009). The objective is to understand behavior as a function of social representations that one seeks to explain with socio-demographic criteria. When one focuses on the role of individual factors, one speaks of psychometric approaches (Fischoff *et al.*, 1978). When one focuses on collective factors, such as values and norms (Michelik, 2008), on speaks of cultural approaches (Douglas, 1992). The objective is to define profiles and groups of individuals as well as criteria that favor pro-environmental attitudes of conservation and protection, so as to best adapt public policy measures that aim to change behavior. Individual characteristics are often important, such as age, sex, education (academic and empirical), and information, the last one being most often related to conservation. Many authors (Dreezens *et al.*, 2005; Dietz *et al.*, 2007; Shwom *et al.*, 2010; Becker and Félonneau, 2011) show that motivations and perceptions about environmental conservation involve values that exceed personal limits. Individuals sensitive to environmental conservation are thus often defined by their altruism compared to individuals more concerned with their own short-term welfare, who in contrast, may be considered egotistical.

Identification of perceptions helps measures and incentives put in place to be better suited and thus better accepted by populations. It especially concerns the following:

(i) describe the degrees of knowledge and recognition of services to be able to define the kind of incentives and awareness activities to provide

(ii) identify certain target groups that need specific support measures
(iii) anticipate circumventing of the norms and inspection measures that will be set up

The identification of perceptions, even though it plays a decisive role in the recognition of these services and the design of related public policies, is not often the focus of specific studies. **According to Balmford *et al.* (2002), this prerequisite phase, however, helps understand the reasons that create interest in preserving ecosystems for human societies and that may help farmers to become "managers of both production and ecosystems"** (Tilman *et al.*, 2002 cited by Dale and Polasky, 2007). In implementation of public policy, relying on common representations eases convergence and thus coordination of behavior (Livet and Thévenot, 2004). It can also be performed as Quétier *et al.* (2009) did, to confront discourses and perceptions with the objectives of environmental public policy. The study of perceptions can rank services as a function of their social importance.

After studying perceptions comes evaluating the value assigned to services before setting up mechanisms for creating value or payment (Beaumont *et al.*, 2007; TEEB, 2010). Previous knowledge of perceptions helps in this case to clarify development of survey protocols implemented to evaluate the value of services rendered. In particular, for combined "choice experiments", which tend to replace contingent evaluations (Sidebar no. 21), the consideration of perception eases identification and ranking of attributes to construct the different scenarios proposed.

Sidebar 21: Evaluating the value of services rendered

The concept of ecosystem services is human-centered. Like the concept of natural capital, it implies a utilitarian approach to the ecosystem, but it does not refer only to the productive sphere but more generally to human welfare. The existence of an ecosystem service depends on the existence of a demand, use (direct or indirect) or recognition of a value (value of choice or value of existence). It is this demand or use that determines the contribution to the welfare of society. The issue of the value of services generates many debates due to the human-centered character of the concept and its consequences for implementation of mechanisms to pay for these services (Maître d'Hôtel and Pelegin, 2012). Two main views of value contrast each other: **instrumental value** (services as means to the ends of uses) and **intrinsic value** (services that sustain issues by their existence). Economic value is essentially instrumental, unlike approaches that assign all kinds of life an intrinsic value, regardless of its social utility. Traditionally, environmental economics defines an overall economic value that includes different components.

TOTAL ECONOMIC VALUE				
Value of use			Value of non-use	
True value of use		Value of choice	Value of legacy	Value of existence
Direct	Indirect			

Evaluation is a decision-aid tool. For ecosystem management, according to Liu *et al.*, (2010), it responds to three objectives: (i) measure and ensure that the scale and magnitude of human activities in the biosphere are environmentally sustainable, (ii) distribute in an even manner rare resources and property rights, and (iii) allocate resources in an effective manner to maximize utility and human welfare. Depending on the situation, the methods used for these evaluations vary.

PREFERENCES SHOWN				PREFERENCES DECLARED
MARKET VALUES		NON-MARKET VALUES		
Direct methods		Indirect methods		Direct methods
Competitive market	Modified market	Substitute markets	Implicit markets	Constructed market
Observed prices	Modified observed prices	Avoided costs, Equivalents, Protection expenses, Changes in productivity	Displacement costs, hedonistic prices, Dose-response	Contingent evaluation, Combined evaluation
		Method for transferring values		

133. EXAMPLE OF PERCEPTIONS OF SERVICES RENDERED BY FISHPOND SYSTEMS

A) *Methodological elements*

During surveys of fish farmers and stakeholders of aquaculture systems studied in the PISCEnLIT project (269 people surveyed), the first question asked respondents to provide keywords that expressed fish farming to them as well as for the regional economy and heritage. Next, they were asked to select from a list of 26 ecosystem services adapted to each site the 10 services that seemed the most important and to rank them in decreasing importance from 1 to 10. From these selections and rankings, two indicators were calculated:

- **frequency of mention**, which counts the number of times each was selected (i.e., judged important)
- **a mean score** corresponding to the sum of the ranked scores

B) *What are the rankings of services according to actors?*

It is possible to compare their perceptions of services according to context and the type of actor by calculating, for each service, the percentage of producers and stakeholders who mentioned the service in each territory (Figures 3 to 5). Given the wide diversity of services, we chose, in agreement with Petrosillo *et al.* (2013), to analyze results by grouping regulating and support services, which are those for which recognition is not explicit and that are non-market. It is thus possible to consider only three categories:

(1) supply services, which create economic opportunities for farms and territories

(2) support and regulating services, whose importance falls under ecological and biophysical dimensions of the ecosystem

(3) cultural services that value heritage and recreation dimensions of ecosystems and territories

[7] In certain cases, especially in Brazil, fish farmers had difficulty ranking services. Consequently, scores per service for this site could not be used due to insufficient data.

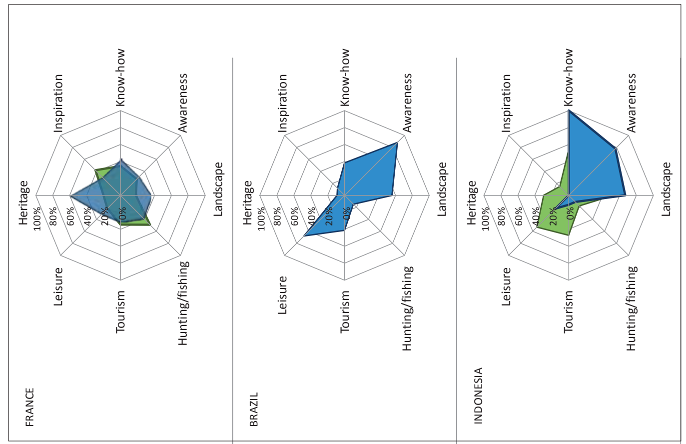


Figure 5: Perceptions of cultural services

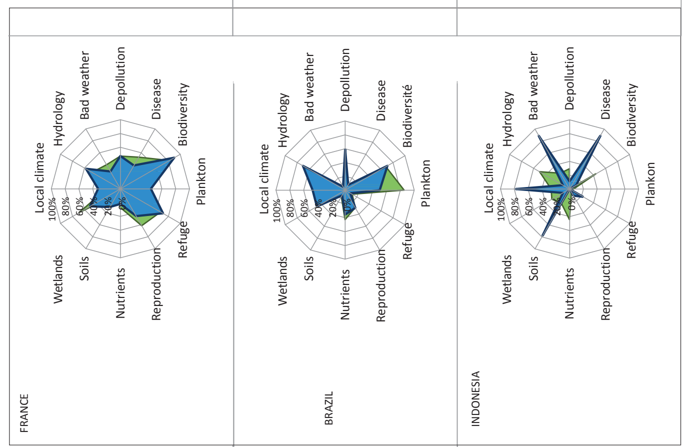


Figure 4: Perceptions of regulating and support services

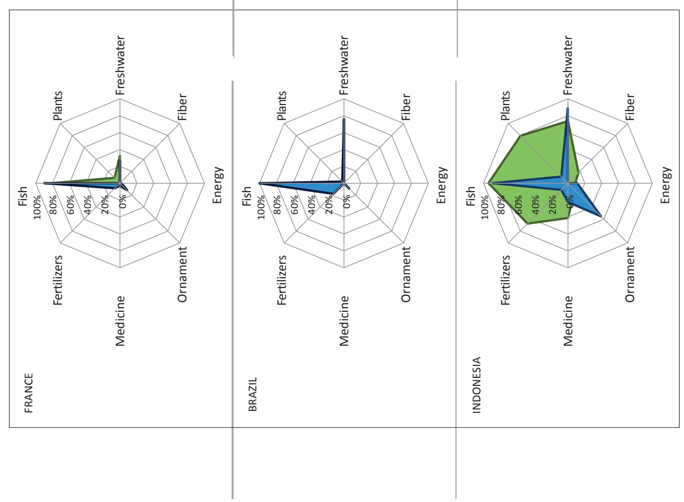


Figure 3: Perceptions of supply services

Legend: % of producers (green) and stakeholders (blue) who selected each service

C) *Analysis of perceptions according to situation and type of actor*

First, **between countries,** there are large differences in perception linked to (i) the type of physical context, which influences the role of the pond (e.g., position in the watershed, size, number of ponds), (ii) the history and age of the fish-production activity, and (iii) the diversity of practices, uses, and public policies related to ponds. Besides fish production, common to all countries, the diversity of supply services is the greatest in Brazil and Indonesia, with functions of freshwater reservoir and fertilizer supply, or plant production in Indonesia. Likewise, the importance of landscape and recreation aspects, as well as leisure-fishing activities and hunting is explained both by lifestyle and the heritage character of ponds built in the Middle Age. In Brazil and Indonesia, recreational aspects are recent and limited to fishing competitions. The importance of know-how is explained by learning issues, which are related to the short history of the type of fish production studied in Indonesia. Finally, profiles of support and regulating services differ greatly as a function of the importance and orientation of environmental public policy (existence of agro-environmental measures in France), type of farm (integrated pig-fish farms in Brazil that focus on phytoplankton production), and contexts (buffer role played by ponds during floods in flood-prone zones in Indonesia).

Between types of actors (fish farmers and stakeholders), differences in representation can be explained by differences in scale of approach, levels and forms of knowledge (family-based or academic), as well as the degree to which the family is involved in fishponds. There are strong similarities in their viewpoints in France and Brazil, where information about ecosystem services is the subject of awareness programs or incentive measures. There are, however, a few differences: for example, stakeholders in France and Brazil have a wider vision than fish farmers about the heritage value of ponds. Likewise, in Brazil, stakeholders are more conscious of the importance of know-how and the part played by the landscape. In contrast, perceptions differ more in Indonesia, where stakeholders and fish farmers do not rank services in the same order. The degree of these differences is due to a certain institutional and cognitive "isolation" of fish farmers who are recently-converted farmers and thus have highly variable educational levels.

These differences in representations show the need to explore a wide diversity in viewpoints. Consideration of this multiplicity can help to understand the diversity of position, which may restrict acceptance of certain management measures.

CHAPTER 2. DEFINITION OF AND INTEREST IN ECOLOGICAL INTENSIFICATION OF AQUACULTURE SYSTEMS

Based on agricultural advances, we shall define the concept of ecological intensification of aquaculture systems in three steps:

(1) proposing a reference framework and generic definition of ecologically intensive aquaculture (§ 21)

(2) identifying the objectives so as to explain the logic and aims that determine behaviors (§ 22)

(3) characterizing implementation methods so as to distinguish specific profiles as a function of fields and degrees of expertise, investment, and learning (§ 23)

21. DEFINITION OF A REFERENCE FRAMEWORK FOR AQUACULTURE

Based on the definitions given for ecologically intensive agriculture, a definition of ecologically intensive aquaculture can be proposed:

Ecologically intensive aquaculture is aquaculture that relies on ecological processes and functions to improve its performance, strengthen ecosystem services rendered, and decrease disservices.

This definition is quite generic and not explicit. In fact, ecological intensification covers a wide range of practices and thus lends itself poorly to precise description, which would be simplistic. Initially, given the many types of extensive or intensive aquaculture in existence (see the Introduction), it is useful to specify which pathways are possible to implement ecological intensification in aquaculture systems. **Indeed, implementation methods are not the same depending on whether the aquaculture system already experienced a classic intensification process (Figure 6, Pathways a) or whether it is an extensive system (Figure 6, Pathways b).**

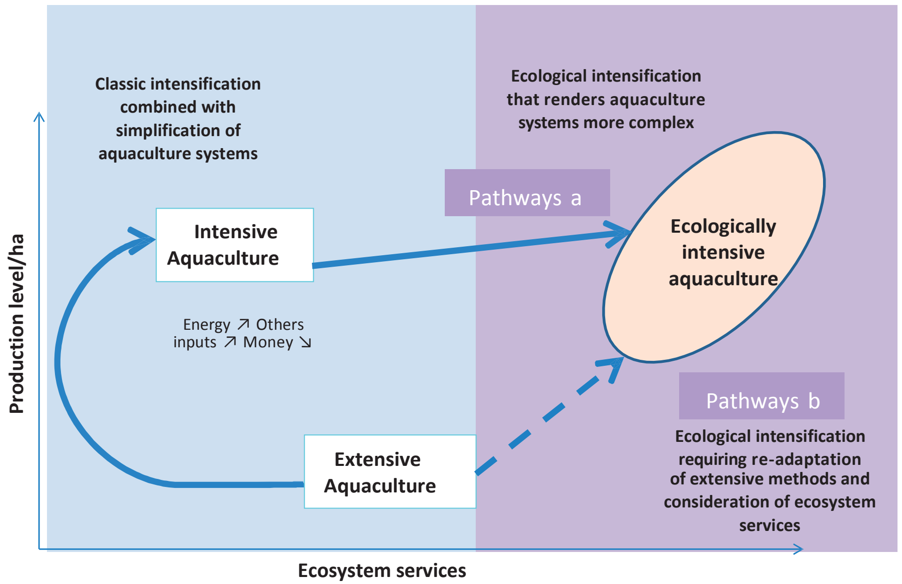


Figure 6: Pathways for implementing ecological intensification in aquaculture

According to Griffon (2013a), implementation of ecologically intensive agriculture implies efforts both quantitative, to increase productivity without increasing negative externalities, and qualitative, favoring product quality while strengthening production of ecological services and amenities (Figure 2). This approach is partially transposed to aquaculture, while distinguishing the following:

- types of resource or receiving ecosystems concerned
- levels of decision, so as to specify the production of ecosystem services related to internal transformations within farms and those that occur at larger scales

It is thus possible to adapt the diagram of Griffon (2013a) to break the process of ecological intensification into different components (Figure 7).

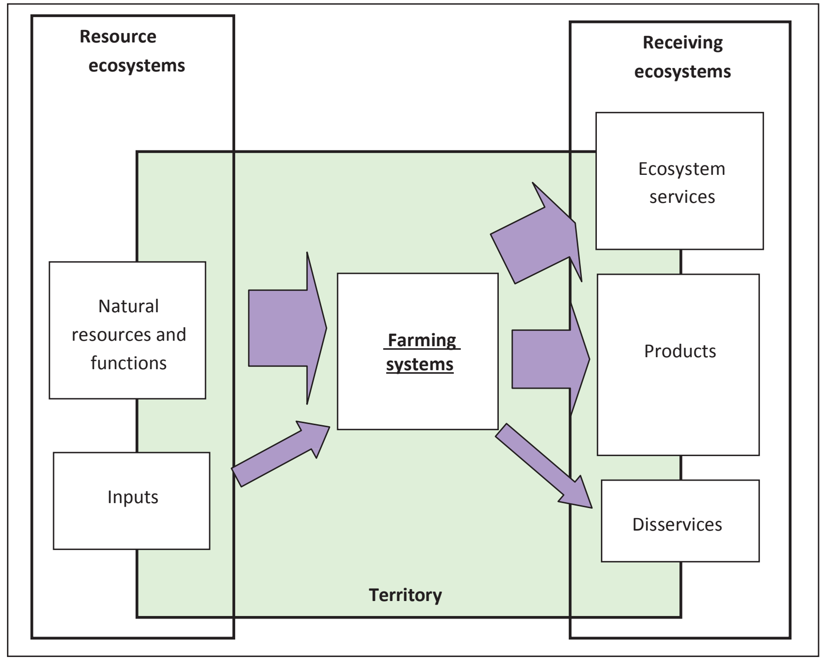


Figure 7: Simplified diagram of links between flows and compartments in an ecologically intensive aquaculture system

These subsystems can be defined as a function of the levels of decision to which they refer, that is, individual decisions within farms or collectives at different scales in territories. One can also distinguish them according to whether they consist of market or non-market products and services, according to the four categories of ecosystem services used by the MEA, or as a function of the positive or negative character of externalities generated. To be as operational as possible, three subsets are identified (market products, ecosystem services, and non-market), corresponding to positive amenities and disservices (Zhang *et al.*, 2007).

211. The "resource ecosystem" compartment

The resource ecosystem (Figure 7) is formed of many ecosystems and covers habitats, functioning, and natural resources that contribute directly to the production system or indirectly via the production of inputs. It can, in particular, be a physical support, furnishing a supply of water or nutrients necessary to the production system. The watershed, for example, a physical support of the ecosystem, influences the physico-chemical quality of the environment around the animal-production system, via its geological and hydrological characteristics. Resource ecosystems also furnish raw materials that make up inputs, especially feed ingredients. However, they can also produce disservices that hamper fish production (Zhang *et al.*, 2007). In the literature, the resource ecosystem corresponds more generally to an interconnection of many ecosystems, which furnish resources to produce input services (Leroux *et al.*, 2008).

212. The "farming systems" compartment

Farming systems vary greatly depending on the species raised and the type of system. In all cases, they have production enclosures (floating cages, ponds, earthen basins, concrete tanks) and mechanisms to manage water and waste. Production densities range from less than 1 kg/m^3 in extensive systems to many hundreds of kg/m^3 in intensive systems. The number of species raised depends on the type of system (monoculture or polyculture), including integrated or multi-trophic systems, in which the choice of species is determined by complementarities in using natural resources and/or production inputs (e.g., fish, algae, mollusks).

213. The "receiving ecosystem" compartment

The receiving ecosystem can be defined as the system that benefits, is impacted, and/or controls the outputs of the farming systems, which are considered inputs of the receiving system. They consist of products (target species), positive externalities (e.g., agricultural systems benefitting from fish-system waste as an amendment), or negative externalities (e.g., escaped fish, organic and inorganic waste).

214. Interactions between compartments

The level of interconnection among resource, farming, and receiving systems depends on their dimensions (spatial and temporal scale). Resource and receiving ecosystems may be:

- geographically and hydrologically independent (e.g., location of production of feed ingredients, and of overflow and destination of aquaculture products)
- contiguous, successive, or separated by the farming system (e.g. river upstream, aquaculture ponds, river downstream
- overlapping or similar (e.g., amphibious and aerial fauna coming from and feed similar environments).

Connections between the receiving and farming systems may be direct (e.g., transfer of fish for restocking, nutrient flows) **or indirect** (e.g., movement of migrating species). For instream intensive salmon production, the residence time in water and the sizes of production basins lead to an upstream-downstream vision of the hydrosystem (resource ecosystem – farming system – receiving ecosystem), despite high externalization of the resource ecosystem (e.g., production of equipment, feed, energy) and receiving ecosystem (destination of waste, products, and co-products). For dam-created ponds, the upstream situation remains, because the watershed, hydro-climatic dynamics, and water management greatly influence hydrological and ecological functioning, in terms of material flows (liquid, solid, and dissolved). However, the increased residence time and surface areas of water (compared to the tributary and outflow) modifies the dimensions of the initial hydrosystem. Terrestrial and aquatic environments near or farm become in turn resource or receiving ecosystems for dynamics of host populations (e.g., plants, birds, insects).

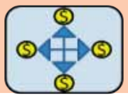
215. The territory

The territory corresponds to a social delimitation of spaces in which aquaculture farms are implanted, as are spaces that interact via flows generated or used by these farms. It is a space used locally by individuals, groups, or social networks and which is the focus of an arrangement of coordination and governance mechanisms that aim for good use and regulation of its resources. From an environmental viewpoint, it is a set of ecosystems that contribute to creation of a landscape and which explains functional interactions. The territory thus corresponds to a unit or interlocking set of units of landscapes as a function of the size of the space and the homogeneity of physical and sediment-related parameters. These parameters influence habitats and, in doing so, the nature and indicators of biodiversity, as well as perceptions and lives of populations. It is at the territorial scale that aquaculture systems co-inhabit and coordinate with other activities and that management objectives and tools of activities and resources are defined and implemented via multi-scale governance mechanisms, whose level of centralization depends on the context. It is in the framework of territorial projects that pathways for contribution by aquaculture systems to strengthening ecosystem services need to be co-constructed. It is also at the territorial level that policies of valorization, conservation and restoration of ecosystems are set up and give rise to definition of appropriate mechanisms for governance of ecosystem services.

22. DEFINITION OF ECOLOGICAL INTENSIFICATION AS A FUNCTION OF THE GOALS SOUGHT

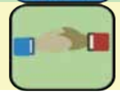
Methods of ecological intensification that cover multiple practices depend first[8] on the objectives and orientations that are sought. It is thus possible to supplement our definition by describing the objectives to which ecological intensification can respond. One can thus list seven objectives or principles that can explain, justify, or legitimize evolution of aquaculture systems toward ecologically intensive aquaculture. These objectives fall under many goals, depending on the scale at which they are involved (farm and/or territory).

At the farmer level, **adoption of ecological intensification practices can be a part of seeking more autonomy, effectiveness or great territorial integration.** These aims can be broken down into four main objectives, defined as follows:

1	**Minimize dependence on external resources**	
2	**Increase performance of aquaculture production systems and product quality**	
3	**Improve robustness, flexibility, and resilience of systems via integration and functional complementarity**	
4	**Diversifier market-oriented ecosystem services of aquaculture systems**	

In contrast, as the territorial scale, collective decisions may contribute sustainable development of territories. The objective is to strengthen conservation of ecosystems by measures of valorization or restoration of ecosystem services, but also to develop green jobs, use heritage resources and amenities of the territory, and develop territorial governance. **Ecological intensification acts here as a territorial project that eases restructuring of the territories in which they are implemented[9].** These more collective motivations help formulate three objectives for contributing to ecological intensification of aquaculture systems and territories:

[8] Other factors can also play a decisive role, such as skill levels or financing capacity.

5	**Promote recognition of services and better use of skills and know-how**	
6	**Improve territorial integration of aquaculture systems by promoting production of non-market ecosystem services**	
7	**Adapt mechanisms and instruments of territorial governance and help stakeholders participate**	

Identification of these seven objectives is important both for clarifying reasons and motivations for ecological intensification and for easing assessment of approaches for ecological intensification. This list of objectives strengthens the precision of our definition of ecologically intensive aquaculture by detailing its components. Its length does not diminish its operational capacity, since it helps in claiming ownership of all dimensions of the concept, not only transformations in practices but the changes in values, skills, and modes of governance that its implementation implies.

Ecologically intensive aquaculture is aquaculture based on ecological functions to improve its productivity, strengthen the ecosystem services rendered, and decrease disservices. The consequences sought focus on greater autonomy and/or greater territorial integration of aquaculture systems. More widely, ecological intensification also contributes to the sustainable development of territories and relies on management of biodiversity and good use of local knowledge. It assumes and contributes to improvement in territorial governance.

In summary, ecologically intensive aquaculture helps produce as much or more (especially via diversification), produce better with respect to respect for sustainable development objectives, and strengthen integration of ecosystems in territories.

[9] One finds here similar dynamics, with, for example, the role of local agriculture in practices of local and territorial development, in interaction with mechanisms such as Natura 2000 projects or national parks, whether national or regional.

23. DEFINITION OF ECOLOGICAL INTENSIFICATION AS A FUNCTION OF IMPLEMENTATION METHODS

It is possible to distinguish three profiles of implementation, which fall into increasing levels of learning and skill.

Profile No. 1: Decrease impacts

Adaptation of practices without calling the production system into question. The fish farmer can choose to act only at the level of inputs and waste, with a process of total or partial substitution of inputs with equivalents generating less environmental disruption or by adding a waste-treatment system in fish farms. Even though its impacts are wider, ecological intensification in this case is centered on the farm. It can be limited to technical changes and, regarding waste control, be encouraged by regulatory norms.

Profile No. 2: Change objectives and practices

Revision of production objectives while searching for closer links with the territory. Transformations caused by ecological intensification act on organization of the function of production at the farm scale. It consists of changing practices and the organization of elements of the aquaculture system, with changes of differing degree of magnitude at the scale of aquatic ecosystems, not just at the farm scale. One can thus seek to diversity production and develop integrated production systems that combine animal and crop production or that combine production of complementary species. Multi-trophic aquaculture offers many examples of these types of practices. One can also find examples of hydroponic systems[10] or recycling of fish-farm waste on crops (sludge recuperation).

Profile No. 3: Multidimensional integration

Change in scale and value allowing multidimensional territorial integration. The consideration of ecosystem services increases even further the field and scale of eco-innovations, which are thus thought about in their territorial dimension at different scales. It consists of strengthening the territorial integration of aquaculture by developing non-market services, especially support and regulating services. By increasing the scale beyond local ecosystems, one contributes to strengthening the phenomena of non-contiguous ecological solidarity (Sidebar no. 19). As seen, the role of fishponds in nesting and conservation of certain migratory birds increases the scale of services rendered by territories with ponds to source or destination territories of these species.

[10] Landless plant cropping systems use fish farm waste as a source of nutrients

Practically, these profiles can be separate or cumulative, as shown in Figure 8, which shows a simplified representation of the organization of these profiles. They can be understood according to increasing scale, from the bottom to the top of the figure, which illustrates an increasing complexity of the processes used and the scales at which the function of aquaculture production must be considered. They can also be described as a function of the nature of eco-innovations, which can come from within the farm or from specific research. Thus, one can distinguish **innovation processes coming from hybridization of former practices or from integration of technological tools, biological processes (especially genetics), or ecological processes (by relying on research from industrial ecology).** Recirculating aquaculture is an example of the type of innovation whose motivations come from outside the farm and thus whose development required much research.

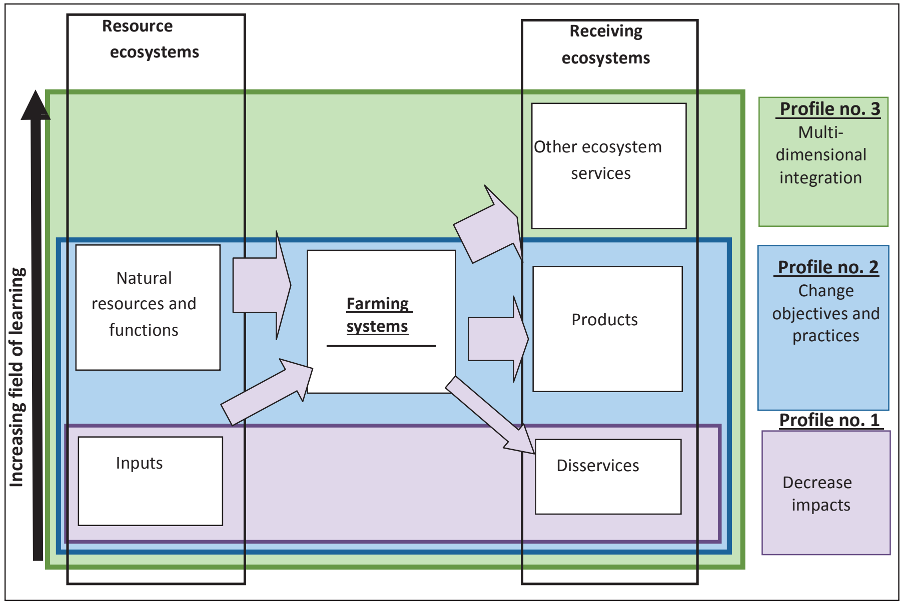


Figure 8: Examples of profiles of ecological intensification of aquaculture

Description of these profiles is obviously simplified, for educational reasons, to show the many pathways for implementing ecological intensification. However, it adds to our definition of ecologically intensive aquaculture:

Ecologically intensive aquaculture is aquaculture based on ecological functions to improve its productivity, strengthen the ecosystem services rendered, and decrease disservices. The consequences sought focus on greater autonomy and/or greater territorial integration of aquaculture systems. More widely, ecological intensification also contributes to the sustainable development of territories and relies on management of biodiversity and good use of local knowledge. It assumes and contributes to improvement in territorial governance. It can consist, for example, of substituting inputs or controlling waste and/or changing farm management to optimize interactions in the aquatic ecosystem by combining diverse species or types of production and/or of voluntarily developing non-market services or strengthening phenomena of ecological solidarity.

CHAPTER 3. IMPLEMENTING A PROCESS OF ECOLOGICAL INTENSIFICATION OF AQUACULTURE SYSTEMS

In this chapter we propose implementation of a process of ecological intensification, by:

(1) explaining the foundations of the approach (§ 31)

(2) describing its steps (§ 32)

Application of these principles of ecological intensification to aquaculture requires several steps in order to adapt the objectives to the needs and specific conditions of aquaculture systems and thus to favor adoption of this model and these practices by system actors and the population of the territories concerned. **It is useful to propose several phases in order to consider general conditions of project management, but also to facilitate the organizational and institutional learning process in a rationale of a collaborative project co-constructed within networks of actors.**

31. ADOPTING ECOLOGICAL INTENSIFICATION IMPLIES A PARTICIPATIVE PROCESS

The collaborative and participative logic responds both to the general philosophy of agroecology (see § 111) but also to conditions of adoption of new values and acceptability of innovations that one may consider radical or in a double loop (Argyris and Schön, 1996 (Sidebar no. 12)). **In fact, implementation of ecological intensification implies change in "professions" but also objectives and the image of the activity. It is not only about applying new farm-management methods or new activities but to collectively build a new**

framework. These new management methods and activities will have sense both individually for farmers and collectively in terms of recognition and social legitimacy of these practices. As mentioned, (see § 112-B), the sociological conditions surrounding adoption of these practices may be restrictive, and it is necessary to set up measures for information and awareness, as well as suitable mechanisms for participation. The importance of a co-construction approach for adopting principles of sustainable development and a shared definition of the principles, criteria, and indicators of sustainable development has been shown (Rey-Valette *et al.*, 2008). One finds here the same foundations and logic in the sense where intensification can be seen both as a "contribution" to implementation of sustainable development (as much for aquaculture farms as for the territories concerned) and as a specific framework that is integrated with the rationale of sustainable development. Thus, definition of key steps of implementation considers these conditions of adoption, especially by introducing phases of co-construction of objectives and actions to set up, but also monitoring indicators. Griffon (2006) recommends accompanying this approach of ecological intensification with an appropriate governance, because these changes in practices carry risks of inertia or diversion that require institutional measures and innovations.

32. THE MAIN KEY STEPS

Implementation of an ecological intensification approach thus implies following a particular pathway with many key phases that alternate (i) activities following a rationale of sharing objectives and knowledge and (ii) more traditional project-management activities. The approach is broken down into six phases (Figure 9):

1 - **Create the support group** and adapt the framework proposed by the guide as a function of the characteristics of the aquatic ecosystem under study.

2 - **Know the characteristics of the aquatic ecosystems** by assessing production systems (issues, constraints on functioning and practices, number of farmers) and systems of territorial governance (formal and informal measures and regulations, level of information, networks of actors, decision processes). This assessment will need to be shared with stakeholders of the system or even co-constructed if not everyone agrees upon the state of the system.

3 - **Co-construct implementation scenarios,** so that principles of ecological intensification are accepted and adopted by the producers and actors in the territories. This co-construction assumes the use of focus groups to collectively identify the paths for implementing ecological intensification. From the reference framework adapted to the context, it is a matter of selecting and ranking the operational objectives and sub-objectives so as to best adapt it to existing practices.

4 - **Identify actions** that can be implemented for each of the objectives, given that some actions may contribute to several objectives or have synergies with each other.

5 - **Develop a monitoring mechanism** (observatory, assessment tool) at the farm scale and at the scale of aquatic ecosystems combining indicators. This monitoring aims to redirect activities (or objectives) as a function of the results and to help disseminate the innovations developed, by identifying the types of effects and rhythm of change.

6 - **Communicate results and practices** so as to facilitate dissemination of practices and strengthen their social recognition.

The following figure presents the structure of these key phases.

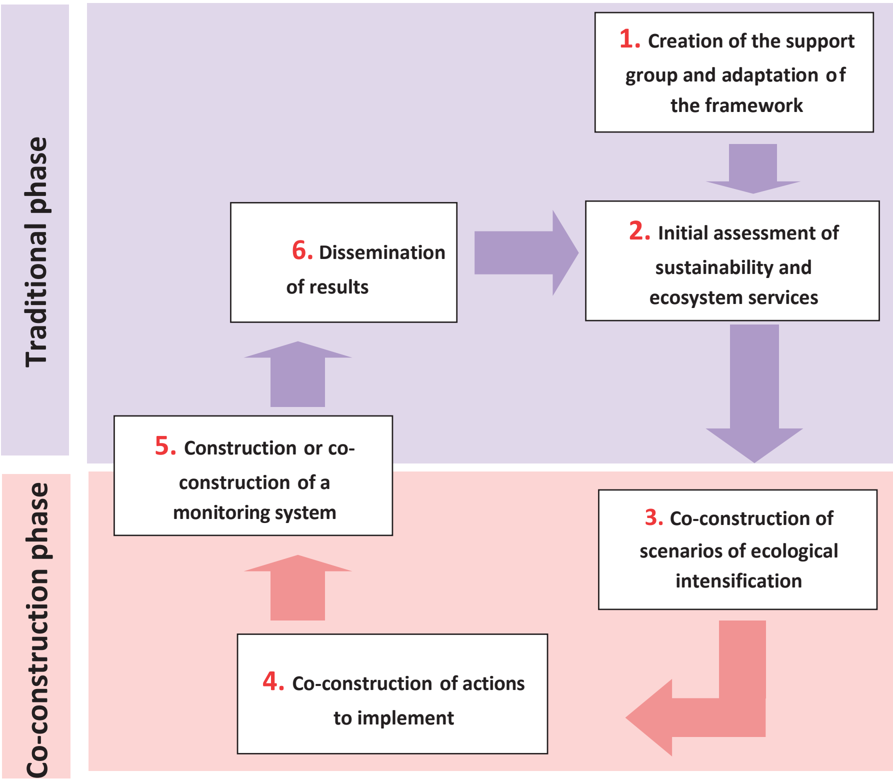


Figure 9: Main steps if implementing an approach of ecological intensification

Our objective in the following points is to recall the general rationale of each phase and to present the tools and approaches specific to ecological intensification. Given the diversity of recipients of this guide (see the foreword), many methodological sidebars will be presented so as to ease reading, regardless of the levels and types of skills of users of this guide.

CHAPTER 4. A FEW KEY POINTS OF THE ASSESSMENT

The assessment phase aims to describe the state of the system to ease identification of objectives and modes of implementation of and support for ecological intensification of aquaculture systems. It aims to integrate (i) aspects coming from **traditional assessment of a sector or production chain** so as to better know farms, their room to maneuver, and their innovation capacity, as well as (ii) certain dimensions of **territorial assessment** to describe the territories in which these farms are located. At this scale, the objective is to study with which ecosystem services interactions are the strongest, the importance of these services for the territory, and how they are perceived. The general methods of the assessment that come from economic or territorial engineering will not be detailed. It is a matter of specifying four specific dimensions that have a strategic role:

(1) **ecological knowledge of the ecosystems** concerned, and that of interactions between farms and fish-farm practices and the ecological functioning of these ecosystems, so as to identify the processes that determine the production of ecosystem services (§ 41)

(2) **knowledge of the perceptions** that fish farmers and stakeholders (or even local populations) have about these services so as to study (i) the social demand for services linked to ecological intensification of aquaculture, (ii) social acceptability of certain measures, and (iii) needs for institutional awareness or change necessary to recognize the contribution of ecological intensification to sustainable development of the territory (§ 42)

(3) **identification of existing practices** within aquaculture farms and assessment of their sustainability (§ 43)

(4) **description of the eco-innovation capacity** of farms and territories, so as to identify objectives and measures, as well as profiles of ecological intensification (§ 44)

41. IDENTIFICATION OF THE MAIN INTERACTIONS BETWEEN FARMS AND ECOSYSTEMS AT THE LEVEL OF BIODIVERSITY AND HYDROLGICAL REGULATION

The current level of ecological knowledge about the functioning of the ecosystems in which aquaculture is located varies according to the context, especially as a function of the mechanisms and measures for conservation that may exist on the territories concerned. In France, for example, the establishment of Regional Natural Parks and Natura 2000 sites benefit from detailed environmental assessments at the territorial scale, even including interactions between territories, such as, for example, the recent establishment of green and blue spaces and Regional Plans for Environmental Coherence. Of course, the environmental assessment to initiate before starting a policy of ecological intensification of aquaculture will differ as a function of the level of pre-existing information. In any case, however, some factors representing the physical and ecological characteristics of territories need to be studied, because they determine the types of functional interactions and types of ecosystem services rendered.

For example, for a pond, the creation and construction method of the pond are a consequence of natural and historic contexts that have become favorable to access to resources: water, space, stock, inputs, knowledge, etc. They explain the position of ponds and their relation with the watershed and watercourses that influence the availability of water for aquaculture farms or the surrounding environment, but also water quality, and more generally certain regulating services (e.g., buffering floods, purifying water). The shape of banks also results from this position, and the method and historic context of its creation. According to the topography of the pond (sheerness of banks), its size and perimeter (linearity), environmental conditions are rendered homogeneous or diverse. For example, in large dam-related ponds, there are banks with low slope and irregular shorelines that favor a habitat mosaic and increase interfaces between aquatic and terrestrial environments. At a larger scale, the initial natural topography and the presence of ponds determine the type of landscape, which can have different degrees of heritage or tourism utility. This is the case for Brenne in France, where one sees a certain morphological homogeneity, with a mosaic of waterbodies, prairies, and forests.

The potential animal-production performances of waterbodies also vary as a function of their ecological forms and contexts, because the effects of trophic interventions (fertilization) will be a function of water depth and more generally the size of ponds. Large differences in functioning of or interest in support services also occur as a function of the general distribution of ponds in the landscape and of the degree of insularity of these environments. This phenomena of insularity is, for example, strengthened in the landscapes with the most hills in Lorraine (France), such as Argonne, in the northern Vosges, where the pond density is lowest. This dispersion is due to the uniqueness of the terrain and the diversity of hydrogeological contexts (cuestas and crystalline massifs, permeable or impermeable sedimentary depressions and plateaus) and leads to fragmentation of conservation spaces.

Sidebar 22: Management of water and ecosystem services for pond aquaculture systems

Water is a heritage object for humanity. Fish farmers stock it during a variable period so that the stock performs its biological functions. Fishponds, especially the oldest ones constructed with dams on watercourses, are located in thalwegs. They buffer the effects of severe floods and low water and help recycle circulating matter. These ponds strongly contribute to the construction and perception of quality of a landscape. Filling and emptying of ponds, development of riparian vegetation, and its control participate in landscape changes and diversify the conditions of biodiversity support. Thus, among birds, molluscivores feed on exposed mudflats, some migratory ducks rest on waterbodies, and marsh birds reproduce in reed beds, etc. These human-managed areas resemble and substitute for wetlands, which humans have made to decrease or disappear elsewhere. Ponds are thus spaces managed by humans in which services of supply, regulation, culture, and biodiversity support complement each other based on simple manipulation of resources (water, space, biodiversity). This perspective should help improve the image of aquaculture, which is dented by water withdrawals, modification of the water balance, and the quality of water returned to the environment.

42. IDENTIFICATION OF PERCEPTIONS/REPRESENTATIONS OF SERVICES RENDERED BY AQUACULTURE SYSTEMS AT THE TERRITORIAL SCALE

Surveys of the perception of services must be performed during the assessment phase so as to have a baseline state of the level of recognition of services rendered by aquatic ecosystems. We will not describe again the importance of these perceptions, which we described previously, nor the specific methodological conditions that they assume (see § 132). It is essential, individually or in a focus group, to rank the list of services rendered once it is adapted to the local context. It consists of identifying the subset of services judged most important by the survey and to rank them in decreasing order of importance. Thus, as the previous example shows (see § 133), this type of survey can be used to calculate indices of frequency of mention (number of times selected) and importance score (mean of scores obtained). As in any survey, its utility and representativeness depends on the sample size but also the social diversity of those surveyed, given the factors determining social representations of the environment (Sidebar no. 20).

43. ASSESSMENT OF FARM ACTIVITIES AND THEIR SUSTAINABILITY SITUATION

431 . Method developed to assess sustainability

In the PISCeNLIT project, we developed an assessment approach for farms based on the environmental assessment methods Life Cycle Assessment (LCA) (Aubin, 2013) and Emergy (Odum, 1996; Wilfart *et al.*, 2012), supplemented by a few social indicators (social LCA approach). The tool developed (Sidebar no. 23) produces several indicators of environmental sustainability and a few socio-economic indicators at the farm scale.

The assessment is based on a precise description of physical elements of the system. The farm is situated in its geographic and climactic context, and its subsystems are described as physical flows into (equipment, infrastructure, chemicals, energy and water use, type of fry) and out of (species raised, pond emptying) of the farm. As for its environmental and economic impacts, particular focus is put on feed to consider the diversity of ingredients used, from both a nutritional and geographic-origin viewpoint, and the industrial processes of feed production.

Pollutants emitted and resources consumed due to fish-production are calculated by relying on mass-balance approaches. This balance estimates the elements emitted (solid, dissolved, or gaseous N and P), and when it is relevant, exported elements, for example, sludge during drying periods in pond production systems. Emissions upstream from the fish-production activity itself (e.g., emissions due to production of inputs necessary for good farm functioning) are also included in the environmental assessment (Sidebar no. 24).

This allows consideration of consequences of different operation strategies, especially feed-related. These flows of polluting emissions, matter, and energy are then aggregated using a well-defined method ("characterization") into impact indicators, such as climate change, eutrophication, acidification, and cumulative energy demand, as well as indicators of damage to human health, ecosystems, and resources.

The Emergy method (Sidebar no. 25) quantifies the level of independence of the system with respect to human-derived resources, the degree of use of renewable (e.g., sunshine, rain, wind) or non-renewable (e.g., soil, groundwater) natural resources. **Thus, the two methods supply complementary assessments: LCA indicates the pressure of the system on the environment, characterized by negative impacts, and Emergy, which reveals the degree to which the system uses the environment in which it is located.** To round off the assessment, animal-production criteria are also calculated, such as the feed conversion ratio, the dry-matter content of the feed, the ratio of waste production, the rate of protein conversion and their efficiency, and the percentage of marine-sourced inputs in feed.

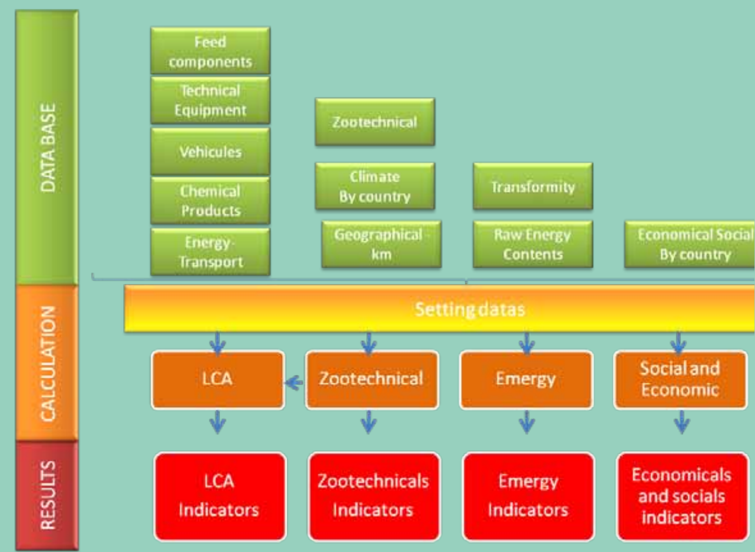
At the level of economic and social aspects, the assessment is based on the principle of Social Life Cycle Assessment (SLCA) (Sidebar no. 26). It contains a few indicators calculated at the farm level and, for each, it is possible to place it at sector and national levels. Thus, besides the turnover and revenue from fish production (as well as total revenue for multi-product farms), it places the assessment in terms of employment by quantifying the human resources employed, contribution to salaried employment, and mean revenue. It is also possible to assess a few social indicators related to work security, renewal rate of the activity, education level, male-female equity, and the percentage of females in the workforce. To ease assessment, all information to collect (animal production and farm operation) and the calculation of the indicators were implemented in a calculator developed in the PISCEnLIT project called PISCE'n'Tool (Sidebar no. 23). The sustainability assessment method and the tool were tested and validated at the project sites (France, Brazil, and Indonesia).

Sidebar 23: Presentation of the tool PISCE'n'Tool

PISCE'n'Tool is usable for all types of aquaculture. It can be applied to extensive pond production systems, as well as more complex systems, such as recirculating systems. It can also consider diverse kinds of association between aquaculture and other terrestrial production systems, whether of animals or plants. The environmental analysis performed by the tool is based on principles of Life Cycle Assessment (ISO, 1997) and Emergy (Odum, 1996). The tool is composed of four parts:

- biotechnical description of the farm
- calculations
- databases
- presentation of results as tables and graphs

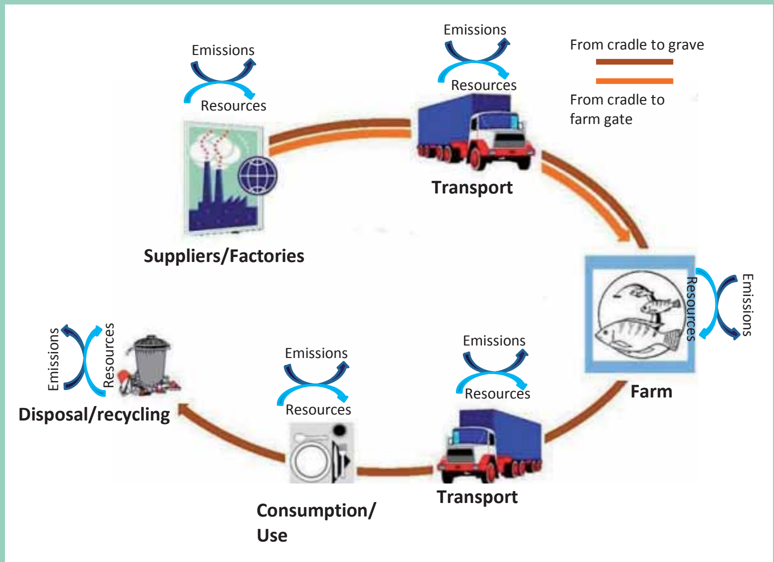
This tool thus allows easy comparison of different aquaculture systems based on a set of ecological criteria (see the following sidebars on Life Cycle Assessment and Emergy), as well as a few economic criteria, so as to better identify the action mechanisms to implement to improve the environmental performance of these systems.



Presentation of the conceptual framework of the tool PISCE'n'Tool.

Sidebar 24: Life cycle assessment

Life Cycle Assessment (LCA) is a method that analyzes implications of potential environmental impacts, consumption of inputs, and pollutant emissions associated with a production or service throughout its life cycle, from the extraction of raw materials to its use and up to its disposal or recycling. It is normalized internationally under ISO 14000.



Presentation of the life cycle of farmed fish

This method is has been applied to agriculture since the end of the 1990s (since 2002 to aquaculture) and is still under development. It is based on calculating groups of indicators called impact categories that cover the main environmental issues and apply at different spatial scales (local, regional, global). These impact categories are calculated by aggregating different products emitted or consumed, proportional to their potential to pollute.

Continuation of Sidebar 24

In aquaculture, the impact categories used frequently are the following:

- eutrophication, expressed in kg of phosphate equivalents (kg PO_4 eq.), which estimates the potential degradation of the aquatic environment by emissions of nutrients (nitrogen and phosphorus), leading to algal proliferation that consumes the available oxygen
- acidification, expressed in kg of sulfur dioxide equivalents (kg SO_2 eq.), which

estimates potential acidification of soil and water due to production of acidifying molecules in the air, soils, or water

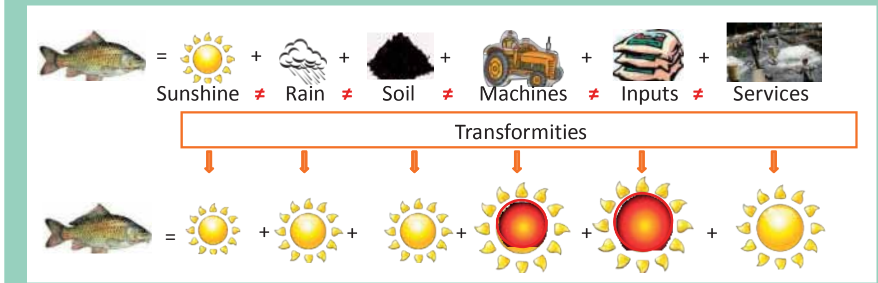
- global warming, expressed in kg of carbon dioxide equivalents (kg CO_2-eq), which estimates production of greenhouse gases by the system
- energy use, expressed in megajoules (MJ), which groups together all energy resources used
- use of net primary production, expressed in kg of carbon (kg C), which reflects pressure on the trophic chain by estimating the quantity of carbon from photosynthesis necessary to produce one unit of mass of the animal considered
- water dependence, expressed in m^3, which defines the water used or that passes through the production system during production, in the case of aquaculture

These impact categories are calculated according to a functional unit, which is generally one metric ton of fish produced. In certain cases, it may be interesting to use surface area as a functional unit, for example for ponds.

The use of LCA in analyses of sustainability of agricultural and aquaculture systems covers many interests. The method defines and formalizes the production system, its components, its limits, and the flow of materials it produces or on which it depends. LCA allows users to go beyond local perception of environmental issues. The many impact categories allow one to get closer to overall interactions with the environment and to analyze relations between impacts, especially by following the risks of transferring pollution between impacts. Taken individually, impact categories can also serve as indicators and enrich indicator systems of social, economic, environmental, and governmental sustainability.

Sidebar 25: The Emergy method

Emergy is based on the thermodynamic principle of Lavoisier (nothing is lost or created, everything is transformed) and is defined as the sum of all forms of energy (direct and indirect, renewable and non-renewable) necessary to perform a service or create a product. It is a quantitative analysis method that determines the value of resources, services, and products, expressed in a common unit: solar Emergy (seJ). Conversion of physical flows (e.g., energy, mass) and economic flows is performed using conversion factors called transformities or UEV (Unit Emergy Value), expressed in seJ/J (or seJ/unit). This conversion factor corresponds to the ratio of Emergy necessary to produce a flow or unit of stock to the true energy of the flow or stock.



The principle of the Emergy method;, example of fish production in ponds (after Ortega (2008), modified by Wilfart *et al.* (2012))

This method has been applied to the analysis of ecosystems since the beginning of the 1980s and to aquaculture systems since the beginning of the 2000s. Analysis is based on a series of indicators that identify how a human-influenced system is situated in its environment and how it uses the resources that come from the latter. These indicators are ratios between flows of total Emergy and flows of Emergy of different system components (Emergy flows from nature (renewable or non-renewable, free), Emergy flows from inputs purchased or imported into the system or between different origins of Emergy flows (free and natural or purchased and manufactured)).

The main indicators are the following:

- Transformity, expressed in seJ/J. It is the ratio of total Emergy flow that passes through the system to the energy in final products of the system
- Emergy Yield Ratio (EYR), which is the ratio of total Emergy flow that passes through the system to the Emergy flow from inputs purchased and imported into the system
- Percentage of renewable Emergy (% R), which reflects the percentage of renewable Emergy in the total Emergy flow

Continuation of Sidebar 25

- Environmental Loading Ratio (ELR), which is the ratio of the Emergy flow from non-renewable natural resources and imported inputs to the Emergy flow from renewable resources
- Emergy Investment Ratio (EIR), which is the ratio of the Emergy flow from purchased inputs to the Emergy flow from (free) natural resources
- Emergy Index of Sustainability (EIS), which is the ratio of the Emergy Yield Ratio to the Environmental Loading Ratio. It shows the trade-off between advantages of the process studied and the pressure on the environment from obtaining it

Sidebar 26: Social LCA

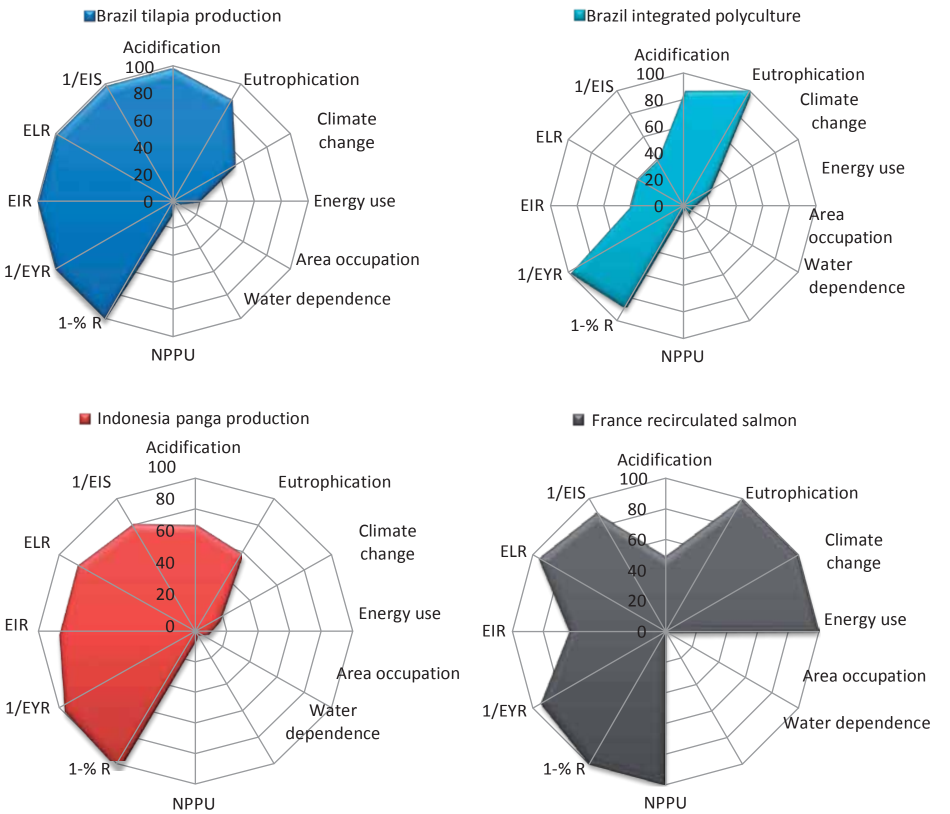
Social Life Cycle Assessment (SLCA) was developed at the end of the 1990s in the context of reflection on sustainability and more particularly on the definition and assessment of corporate social responsibility. SLCA aims to assess the "social effects of different human groups due to the functioning of the life cycle of a product". Macombe and Loeillet (2013) highlight four interests of SLCA: (i) identify the possible improvement points of social effects and simultaneously avoid transfer of negative effects from one life cycle to another, (ii) inform private decision makers and governmental and non-governmental organizations, (iii) identify indicators relevant for social effects, and (iv) develop new marketing tools via labeling, for example. There are two schools of thought. **Those following attributional SLCA** (Benoit *et al.,* 2010; Norris, 2006) represent the first school. It aims to assess within a sector the value of indicators that correspond to impact categories found in national laws and codes or international conventions, for example, child labor, forced labor, or worker's rights. The work of UNEP (United Nations Environment Programme) and SETAC (Society of Environmental Toxicology and Chemistry) supply guidelines that facilitate construction of these attributional SLCA indicators (Benoit *et al.,* 2010) and a database containing indicators for different sectors (http:// socialhotspot.org/). **The second school groups consequential approaches** (Macombe, 2013a; Jørgensen *et al.,* 2010; Dreyer *et al.,* 2010), which seek cause-and-effect links between production variables and social impacts via significant statistical relations called *pathways*. The indicators used come from national general statistics and are the subject of econometric analyses that are used to compare sectors. The two schools also differ in the scale at which analysis is performed; the former focuses at the farm level, while the second focuses on the sector.

SLCA differs from environmental LCA in several ways:

- SLCA also considers positive impacts
- indicators may be ambiguous, depending on the context, and sometimes pose ethical questions, for example, for indicators of minimum waste or the percentage of immigrant workers
- demonstrating the validity of *pathways* and quantifying impact indicators is often difficult and heterogeneous
- measurement corresponds to the difference between an initial baseline situation and the current observed situation, unlike LCA, in which one considers only the existence of the product or not

432. A few examples of results for the aquaculture systems studied

Assessments were performed at each study site (approximately 15 farms per site) by following the method described previously. They allowed calculation of mean environmental profiles and comparison of the systems. The monoculture fish-production systems (tilapia in Brazil, panga in Indonesia) in ponds have similar profiles: eutrophication and acidification impacts were higher than other impacts. Likewise, Emergy indicators were extremely high. These systems do not use well the surrounding environments (little use of renewable inputs, strong dependence on manufactured resources, high stress on the environment). The other systems had more contrasting profiles. The Brazilian system integrating pig production with polyculture fish production had lower impacts for climate change, energy use, surface-area occupation, and water dependence. In contrast, eutrophication and acidification impacts were high as was dependence on manufactured products. The profile of French pond systems was rather different. These are extensive systems (high surface-area occupation and water dependence), which in contrast had lower impacts per unit of fish produced for climate change, eutrophication, and acidification. They are based on using natural resources, depending little on manufactured inputs, and ultimately have low stress on the environment. Overall, pond systems depend little on feed containing a high proportion of productions of marine origin. Finally, the recirculating production system for salmon had a unique profile. It is a system that occupies little surface area but whose impacts of climate change, eutrophication, and energy use are higher than those of other systems. It is a highly managed system whose functioning depends little on the external natural environment, but greatly on the socio-economic sphere. Finally, regarding the species raised, a carnivore, it is also a system using a feed that contains a high proportion of inputs of marine origin.



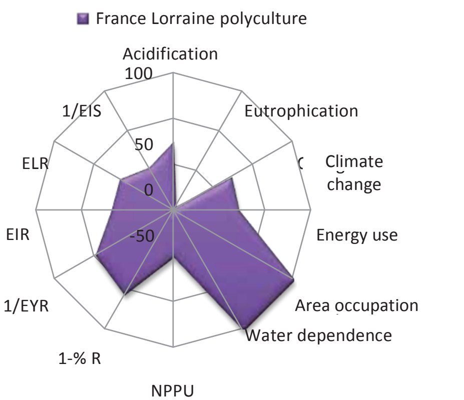


Figure 10: Mean environmental profiles

calculated for one ton of fish produced in different types of aquaculture systems. Results are expressed as a percentage of the profile with the highest impact for each indicator (100 being the highest impact, 0 the lowest) Certain Emergy indicators were transformed to change in the same direction as LCA impact categories

Legend: NPPU: net primary production use, %R: % renewable Emergy, EYR: Emergy Yield Ratio, EIR: Emergy Investment Ratio, ELR: Environmental Loading Ratio (Sidebars no. 24 and 25).

Calculation of these environmental profiles based on system practices allows for fine analysis of consequences of choice of functioning and comparison of diverse techniques and strategies of animal production. This analysis is essential for implementation of strategies of ecological intensification of fish production. **Regardless of the objectives, this implementation needs to decrease impacts per unit produced, decrease dependence on manufacture inputs (dependent on the economy) and better use of natural capital.**

44. IDENTIFICATION OF CAPACITIES FOR AND LIMITS TO ECO-INNOVATION

Adoption of practices of ecological intensification implies for companies and territories processes of change and innovation for which it is necessary to identify constraints or factors that facilitate the process during assessment. **Recall that ecological intensification implies a special process of innovation, mostly oriented toward eco-innovations** (see § 112) that involves specific factors or properties that remain little studied. A few agriculture-related works can be used to identify the types of factors to study at the individual and territorial scales. Of course, the traditional factors influencing adoption of innovations (age, education, financial capacity, etc.) can also be involved. The following table presents the main specific factors to study.

Table 3: Main factors that facilitate eco-innovations

Scale of farmers or farms	Scale of territories
Previous professional experience Proximity of research and specific support organizations Participation in networks Independence from the upstream part of the sector (cooperative, traders) Openness of the farm implying direct contact with clients and local inhabitants	Existence of a professional community and networks open to the environmental dimension Capacity of networks or organizations to implement collective experiments, develop local reference values, and disseminate information Capacity of professional organizations to help professions change Existence of adapted incentives and government programs
Importance of representations favoring the environment and awareness of biodiversity	

The importance of the role of these factors will depend on the profiles of implementation of ecological intensification that we defined. For profile no. 1, it consists of occasional innovations responding, for example, to a strengthening of regulations, for which the previous factors are little involved. In contrast, these factors must be studied for profiles nos. 2 and 3 (Figure 7), which implies greater changes, both in practices and objectives, and even in values.

CHAPTER 5. CO-CONSTRUCTION OF SCENARIOS OF ECOLOGICAL INTENSIFICATION

Implementation of ecological intensification first involves forming, collectively if possible, objectives and thus selecting scenarios. We present this initial and decisive step in three stages:

(1) proposing a few ways to implement co-construction of scenarios (§ 51)

(2) specifying how to break the objectives down into operational sub-objectives (§ 52)

(3) providing a few examples of issues and scenarios (§ 53).

51. A FEW WAYS TO IMPLEMENT CO-CONSTRUCTION OF SCENARIOS

We broadly emphasized the interest of co-construction for facilitating adoption of scenarios by fish farmers and their recognition by actors in the territories in which ecological intensification is undertaken. This co-construction assumes establishment of a participative approach or consultation with the fish farmers, who need to be prepared so as to facilitate dialogue and promote a diversity of viewpoints. Many methods for leading consultations or action programs exist related to development of consultation and participative-democracy practices within organizations but also territorial projects. Design of territorial participation and governance is thus being formalized. It covers "the set of methods and tools that allow for coordination, participation, and learning by actors as well as the management of territorial projects" (Rey-Valette *et al.*, 2011).

We will not detail the many existing methods and practices, which constitute a domain it itself and are difficult to summarize due to the diversity of approaches. This diversity is essential, because these practices must be adapted or hybridized as a function of the contexts and issues so as to facilitate learning. The important thing is to create a climate that favors dialog and reflection while including management of the process to make it operational. Recall that the main criterion that distinguishes consultation processes differentiates (i) **systems aiming to express the diversity of issues** (relatively easy to organize, since they are less exposed to conflicts and strategic positions) from (ii) **more sensitive systems seeking to arrive at a consensus.** Co-construction of scenarios of ecological intensification of aquaculture is located in-between. In fact, there is no need to have a consensus, but it is necessary to be able to define a reasonable number of scenarios at the territorial scale so as to be able to promote exchanges of experiences during the experiment, synergies between practices, and social valorization of these practices within territories.

52. BREAKING OJBECTIVES DOWN INTO OPERATIONAL SUB-OBJECTIVES

Among the results of participatory design, it is recognized that discussions need to be partially supervised, often via physical supports that allows each person to express him/herself. In contrast, situations of free speech are often monopolized by a few individuals or fall prey to digressions. Preparation of suitable supports from which participants make choices and/or rank options constitutes one effective way to manage discussion. thus, co-construction of scenarios of ecological intensification can rely upon the table presented next (Table 4), once it has been adapted as a function of the situation. This table shows a few examples of operational objectives for the seven objectives of reference that we defined for ecological intensification of aquaculture systems (§ 22). Thus, participants chose a few options while working to express sub-objectives that come from individual choices within farms and collective sub-objectives at the territorial scale to strengthen, legitimize, finance, and coordinate individual strategies.

Table 4: Table of operational sub-objectives supporting co-construction of scenarios

<table>
<tr><th colspan="6">O1. Minimize dependence on external resources</th></tr>
<tr><td colspan="3">O1.1 Promote use of inputs from non-human sources</td><td colspan="3">O1.2 Choose local resources as inputs and ecosystem functioning</td></tr>
<tr><th colspan="6">O2. Increase performance of aquaculture production systems and product quality</th></tr>
<tr><td colspan="3">O2.1 Facilitate/encourage biotechnical changes that promote an increase in farm economic performance</td><td colspan="3">O2.2 Increase and better use the quality of products: nutritional, flavor, health, and ease of processing</td></tr>
<tr><td colspan="3">O2.3 Reduce waste</td><td colspan="3">O2.4 Develop a culture of assessment and monitoring</td></tr>
<tr><th colspan="6">O3. Improve robustness, flexibility, and resilience of systems via integration and functional complementarity</th></tr>
<tr><td colspan="3">O3.1 Better use synergies: species, habitats, functions, services, practices, etc. so as to optimize use of trophic levels and habitats</td><td colspan="3">O3.2 Strengthen the adaptation capacity of aquaculture systems
O3.3 Decrease environmental impacts of the aquaculture system</td></tr>
<tr><td colspan="3">O3.4 Promote the capacity for resilience of receiving ecosystems</td><td colspan="3">O3.5 Stop risks of escape of at-risk species</td></tr>
<tr><th colspan="6">O4. Diversify market-oriented ecosystem services of aquaculture systems</th></tr>
<tr><td colspan="3">O4.1 Diversify production practices (on the same site)</td><td colspan="3">O4.2 Diversify products by developing market-oriented cultural services (leisure)</td></tr>
<tr><td colspan="3">O4.3 Diversify products by valorizing co-products</td><td colspan="3">O4.4 Diversify markets</td></tr>
<tr><th colspan="6">O5. Promote recognition of services and better use of skills and know-how</th></tr>
<tr><td colspan="3">O5.1 Identify and valorize the services associated with territories</td><td colspan="3">O5.2 Use and adapt traditional know-how to develop practices better suited to territories</td></tr>
<tr><td colspan="3">O5.3 Use information systems, spatialize services, and adapt territorial assessments used to support territorial planning</td><td colspan="3">O5.4 Improve the eco-innovation capacity of fish farmers and other stakeholders of the territory</td></tr>
<tr><th colspan="6">06. Improve territorial integration of aquaculture systems by promoting production of non-market ecosystem services</th></tr>
<tr><td colspan="3">O6.1 Manage competition between supply services and other services in the territory and between territories</td><td colspan="3">O6.2 Develop supporting ecosystem services that promote biodiversity</td></tr>
<tr><td colspan="3">O6.3 Develop regulating ecosystem services</td><td colspan="3">O6.4 Develop cultural ecosystem services and the attractiveness of territories</td></tr>
<tr><th colspan="6">07. Adapt mechanisms and instruments of territorial governance and help stakeholders participate</th></tr>
<tr><td colspan="2">O7.1 Promote participation in systems of territorial governance</td><td colspan="2">O7.2 Identify and assess the services associated with territories with local actors</td><td colspan="2">O7.3 Set up certification systems that recognize certain ecosystem services</td></tr>
<tr><td colspan="3">O7.4 Manage biodiversity and resources at the territorial scale</td><td colspan="3">O7.5 Set up adapted information systems to facilitate monitoring of implementation of ecological intensification</td></tr>
</table>

53. A FEW EXAMPLES OF SCENARIOS OF ECOLOGICAL INTENSIFICATION OF AQUACULTURE

During the PISCEnLIT project, scenarios of ecological intensification were co-constructed with fish farmers and stakeholders of the territories involved. In a logical manner, the scenarios result from the main issues highlighted in each territory. Certain scenarios appeared relatively specific for a given context, while others seemed more shared and transversal. Four scenarios for pond production are presented below.

The first scenario aims for greater integration in territories (watersheds of a hydrosystem, for example), especially of polyculture ponds, via a **real recognition of the services rendered by these aquatic ecosystems.** The main services targeted concern regulating services (quality and quantity of water flows) and support services (biodiversity). Application of such a scenario will require prior quantification (i) of the ecological value of aquatic ecosystems and their compartments (zones with and without macrophytes, peripheral zones of waterbodies, etc.) and (ii) flows of water and associated material (organic matter or minerals, suspended or dissolved, contaminants, etc.). One perspective of this scenario is to associate the hunting-oriented use of aquatic ecosystems with cultural services such as organization of wildlife observatories (ecotourism). Implementation of new practices (e.g., open-water fishing, activity zoning) seems necessary to search for compromises in management of aquatic ecosystems. This scenario seemed a priority for stakeholders of the French territories studied, with, in Lorraine, the issue of the status of dam-related ponds as a remediation structure at the scale of management of a watershed.

The second scenario aims to increase supply services (aquaculture production) by **developing combined animal-production systems** (Sidebar no. 27) by defining semi-intensive or intensive animal-production zones (enclosures or tanks) within a larger aquatic ecosystem managed extensively. The intensive production would be targeted at species with high economic value (e.g., perch in Europe). Confined animal production would protect the resource, especially from predators (piscivorous fish) and to optimize management of inputs (feed). The fundamental principle of these combined systems rests in the use of the purifying capacity of the aquatic support ecosystem receiving the waste from zones of intensive animal production[11]. This combination can be envisioned either by introducing an enclosure or tank into a larger ensemble ("pond-in-pond" system) or by combining two entities side by side. The entity dedicated to treatment also constitutes a unique ecosystem that can be associated with a unique biodiversity or be the support of complementary extensive animal production (generally with species of lower trophic levels). In both situations, a dynamic circulation of flows of water and waste associated with the intensive animal production is recommended.

[11] As early as the 1980s, the Israeli "Dekel" system experimented with this type of process.

Sidebar 27: Animal-production systems combined or integrated with fish production in ponds

Development of combined aquaculture systems represents a pathway for ecological intensification relevant for fish production in ponds. It associates semi-intensive or intensive animal production confined in a smaller volume with traditional extensive management of a polyculture pond. This combination allows a more rational use of the purifying capacity of ponds. In such a complex system, intensive animal production is performed in a tank integrated into the pond with a certain level of technical requirements (formulated feed, water circulation and oxygenation) and targeted at species with high added-value such as perch. The species produced in the tank is protected from predators (cormorants). This type of combined system has been developed in the United States (Füllner *et al.*, 2007) and in Eastern Europe. Development of these combined systems requires studying the purifying capacity of ponds.

Example of a system producing perch in Germany

The third scenario begins with the major principle that the most available and least expensive energy is solar energy, and consequently that the biomass on which the aquatic ecosystem should main rely for an ecological intensification approach is aquatic plant production, especially macrophytes, phytoplankton, and periphyton. One primary objective is to exploit the large masses of phytoplankton observed more or less continuously during a production cycle, depending on the geographic and climatic context. This scenario leads to reconsidering the choice of species raised by promoting herbivorous species or those with a greater herbivorous tendency or to promote certain physiological stages in certain species so as to favor the development stages that consume the most phytoplankton. Consequently, other methods for managing reproduction of these species need to be developed to ensure spreading out of egg laying and greater availability of the physiological stages of interest. From our viewpoint, it will be necessary to reconsider changes in feeding of many species without considering their "fish-production" statuses. A species currently considered undesirable could be quite interesting in this scenario (e.g., herbivorous carp, bream).

The last scenario is based on **using "natural" inputs** via tributaries of the aquatic ecosystem (from the watershed and the upstream ecosystems or agro-ecosystems) and on **recycling of matter stocked in aquatic ecosystems** (e.g., organic matter and minerals of sludge). Accumulation of sludge stocked in the sediments and very slowly degraded in a hypoxic or anoxic environment becomes a major issue. Also, this material is often lost during fish catching or drying out periods. It could constitute a real base for production of invertebrates, and its mineralization at the base of plankton production, which could become the base of new trophic chains and thus an aquaculture production.

Sidebar 28: Difference between allochthonous and autochthonous species

A species is considered autochthonous in a given environment if it has reproduced there since the Holocene (10,000 years BP). A species is considered allochthonous if it reproduces and has persistent populations in an environment more recently than the Holocene. Allochthonous species result mainly from the introduction of species by humans.

CHAPTER 6. DEFINITION OF ACTIONS AT FARM AND TERRITORIAL SCALES

It is of course impossible to identify all actions that would allow for implementation of ecological intensification of aquaculture systems. Consisting of an approach from an innovation plan, examples of actions are presented according to the logical framework coming from project design (UE, 2004). It consists of breaking down each objective into sub-objectives and to link each action to one of the sub-objectives. This approach offers an analytical and functional definition of the action plan, which at all times allows users to link objectives, means of implementation, and results. Two levels of decision and organization are differentiated by defining the following:

(1) actions mostly defined at the scale of aquaculture farms (§ 61)

(2) actions mostly at the scale of territories and ecosystems concerned by aquaculture (§ 62)

61. IMPLEMENTATION OF ECOLOGICAL INTENSIFICATION AT THE FARM SCALE

The farm scale allows consideration of internal changes, some of which may be decided collectively by a group of fish farmers or result from changes in regulations or even fit in with plans of the territory in which the farms are located. The actions implemented act direction on the production function of the farm. The following tables offer a range of examples of actions for the four objectives defined.

O1. Minimize dependence on external resources

Sub-objectives	Examples of Actions
O1.1 Promote use of inputs from non-human sources	**O1.1 – A1** Raise species of low trophic levels **O1.1 – A2** Shorten trophic chains in the farm system to decrease pressure on feed sources of marine origin **O1.1 – A3** Use renewable energy resources rather than fossil energy resources **O1.1 –A4** Decrease use of medicines and chemical treatments by developing biotic interactions to combat pests, pathogens, or external predator species **O1.1 – A5** Promote use of autochthonous species
O1.2 Use natural or local resources as inputs as well as ecosystem functions	**O1.2 – A1** Use local therapeutic resources (e.g.. phytotherapy) **O1.2 – A2** Direct trophic chains to uses natural resources within production systems **O1.2– A3** Use nutrients from the environment (watercourses, sludge, etc.) and use amendments available on the farm or from the territory (slurry, manure, etc.) rather than industrial products **O1.2 – A4** Develop integration between agriculture and aquaculture, for example by promoting associated animal production **O1.2 – A5** Choose species to produce that have complementary in trophic levels; strengthen and optimize polyculture practices **O1.2 – A6** Promote use of autochthonous species **O1.2 – A7** Use recycling to avoid negative externalities

O2. Increase performance of aquaculture production systems and product quality

Sub-objectives	Examples of actions
O2.1 Facilitate/encourage biotechnical changes that promote an increase in farm economic performance	**O2.1-A1** Optimize practices by reflecting on them and developing technical skill **O2.1-A2** Consider the difficulty and complexity of work in the technical solutions proposed **O2.1-A3** Divide the production systems into segments to optimize each compartment
O2.2 Increase and better use the quality of products: nutritional, flavor, health, and ease of processing	**O2.2-A1** Implement certification mechanisms **O2.2-A2** Reduce risks linked to markets by developing short selling chains **O2.2-A3** Set up traceability of origin and quality of inputs (feed and chemicals) **O2.4-A4** Develop assessment systems that combine assessment of environmental quality and animal production
O2.3 Reduce waste	**O2.3-A1** Combine different production practices or compartments **O2.3-A2** Change practices to use as much formulated feed or energy to produce more aquatic products or to use less formulated feed or energy to produce the same quantity of aquatic products (tons of target species) **O2.3-A3** Use recycling in the farm system to reduce negative externalities (waste) **O2.3-A4** Recycle nutrients with the production system (polyculture, integrated systems) to benefit from additional production
O2.4 Develop a culture of assessment and monitoring	**02.4-A1** Develop systems of combined monitoring and assessment of the environmental quality and production of animal-production systems **02.4-A2** Set up indicators to monitor water quality, the state of fish health, and the final quality of products **02.4-A3** Develop tools that promote auto-assessment practices

O3. Improve robustness, flexibility, and resilience of systems via integration and functional complementarity

Sub-objectives	Examples of actions
O3.1 Better use synergies: species, habitats, functions, services, practices, etc. so as to optimize use of trophic levels and habitats	**O3.1-A1** Develop multi-trophic animal-production systems and optimize use of different species in the trophic chain and of habitats **O3.1-A2** Develop the use of aquatic plants for their roles as water purifier, food resource, or biodiversity support **O3.1-A3** Adapt practices of production or maintenance to the timing and dynamics of ecosystems
O3.2 Strengthen the adaptation capacity of aquaculture systems	**O3.2-A1** Diversify species communities and habitats **O3.2-A2** Diversify farm products **O3.2-A3** Maintain animal welfare and the health status of animal-production systems **O3.2-A4** Maintain hydrological regulations (regulate flows) **O3.2-A5** Promote adoption of practices that benefit biodiversity **O3.2-A6** Adapt animal-production techniques to local conditions
O3.3 Decrease environmental impacts of the aquaculture system	**O3.3-A1** Optimize polyculture by choosing species with complementary trophic levels to reduce waste **O3.3-A2** Use resources within the system with low environmental impacts **O3.3-A3** Decrease the use of antibiotics and promote the use of phytotherapy using local species **O3.3-A4** Adapt the production level to the load capacity of the receiving environment **O3.3-A5** Reduce emission of chemical products
O3.4 Promote the capacity for resilience of receiving ecosystems	**O3.4-A1** Locally use waste from the production system as input to other production systems (external aquaculture recycling or not) **O3.4-A2** Improve the resilience capacity of the receiving environment by environment modifications and restoration measures **O3.4-A3** Use fish-farm water and sludge for other terrestrial crops
O3.5 Stop risks of escape of at-risk species	**O3.5-A1** Adopt methods to combat invasive species **O3.5-A2** Promote the use and raising of autochthonous species **O3.5-A3** Set up efficient methods to control escape of production-system species **O3.5-A4** Avoid spreading parasites and pathogens from animal-production systems

O4. Diversify market-oriented ecosystem services of aquaculture systems

Sub-objectives	Examples of actions
O4.1 Diversify production practices (on the same site)	**O4.1-A1** Segment the production space **O4.1-A2** Combine different practices with complementary management of resources (water, habitats) according to the biological needs of species and development stages
O4.2 Diversify products by developing market-oriented cultural services (leisure)	**O4.2-A1** Increase public access to farms **O4.2-A2** Set up observation sites without bothering wildlife **O4.2-A3** Develop ecotourism
O4.3 Diversify products by valorizing co-products	**O4.3-A1** Diversify farm production and activities **O4.3-A2** Use water rich in nutrients or dried pond sludge to fertilize crops in the territory
O4.4 Diversify markets	**O4.4-A1** Strengthen short selling chains **O4.4-A2** Develop processing activities **O4.4-A3** Set up certification mechanisms **O4.4-A4** Develop other markets for animals and plants: restocking, ornamental, trees for restoration needs, etc.

62. IMPLEMENTATION OF ECOLOGICAL INTENSIFICATION AT THE TERRITORIAL SCALE

Implementation of ecological intensification can be envisioned or strengthened by including it in territorial projects, especially to help them move toward sustainable development objectives. For example, in the state of Santa Catarina in Brazil, these practices can benefit from the existence of funds for environmental services (Law no. 15133 of 19 January 2010, which falls into a rationale of payment for environmental services (*Programa Estadual de Pagamento por Serviços Ambientais*)) and credit programs for family agriculture (PRONAF) that aim to make farmers rural administrators. In France, these actions can have synergy with action plans of conservation programs, such as Natural Parks or Natura 2000 sites, by benefitting from agro-environmental measures, or more generally with local-development strategies that aim to use heritage resources, especially in certain zones that seek alternatives to development of the residential economy.

O5. Promote recognition of services and better use of skills and know-how

Sub-objectives	Examples of actions
O5.1 Identify and valorize the services associated with territories	**O5.1-A1** Assess knowledge about and recognition of services in the territory **O5.1-A2** Identify motivations of actors for developing non-market services **O5.1-A3** Set up awareness programs to strengthen recognition of ecosystem services by territorial producers, populations, elected officials, administrators, and municipalities **O5.1-A4** Improve the image of the aquaculture sector **O5.1-A5** Set up mechanisms to improve economic use of ecosystem services (e.g., agro-environmental measures) **O5.1-A6** Mobilize research and training
O5.2 Use and adapt traditional know-how to develop practices better suited to territories	**O5.2-A1** Facilitate access of fish farmers to information about pathways of ecological intensification **O5.2-A2** Know and analyze former practices to identify interesting ones and promote their recognition and adoption
O5.3 Use information systems, spatialize services, and adapt territorial assessments used to support territorial planning	**O5.3-A1** Adapt or create territorial observatories to facilitate consideration and monitoring of ecosystem services **O5.3-A2** Identify and insert the role of aquaculture systems in territorial development
O5.4 Improve the eco-innovation capacity of fish farmers and other stakeholders of the territory	**O5.4-A1** Make better use of and stimulate capacity for change by facilitating development of farm networks (identify the key actors) **O5.4-A2** Set up local references of ecological intensification **O5.4-A3** Strengthen training, allow acquisition of new knowledge, ease dissemination of knowledge to strengthen technical skills and adoption of the processes and concepts of ecological intensification

O6. Improve territorial integration of aquaculture systems by promoting production of non-market ecosystem services

Sub-objectives	Examples of actions
O6.1 Manage competition between supply services and other services in the territory and between territories	**O6.1-A1** Set up systems for governance and consultation **O6.1-A2** Set up compensation systems **O6.1-A3** Assess knowledge about and recognition of services in the territory
O6.2 Develop supporting ecosystem services that promote biodiversity	**O6.2-A1** Use ecological functions at the farm scale to increase or maintain biodiversity and support services **O6.2-A2** Maintain or develop plant zones on pond banks **O6.2-A3** Reduce practices that do not help maintain the diversity of species and habitats **O6.2-A4** Define the area of habitats necessary for ecological functions **O6.2-A5** Maintain ecological corridors and ecosystem infrastructure **O6.2-A6** Manage biodiversity at the territorial scale
O6.3 Develop regulating ecosystem services	**O6.3-A1** Adapt hydrological management of authorities by considering the functions of hydrological and climatic regulation **O6.3-A2** Promote purification of the aquatic environment
O6.4 Develop cultural ecosystem services and the attractiveness of territories	**O6.4-A1** Maintain landscape structures **O6.4-A2** Promote maintenance of components with heritage value (buildings, festive or culinary practices, habitats and landscapes, conservation of interesting and/or emblematic species)

O7. Adapt mechanisms and instruments of territorial governance and help stakeholders participate

Sub-objectives	Examples of actions
O7.1 Promote participation in systems of territorial governance	**O7.1-A1** Set up or develop mechanisms and instruments facilitating participation of actors, especially fish farmers
O7.2 Identify and assess the services associated with territories with local actors	**O7.2-A1** Identify perceptions and motivations of actors in development of non-market services **O7.2-A2** Promote social recognition of ecosystem services **O7.2-A3** Perform assessment of territories and actor systems **O7.2-A4** Set up mechanisms to use services to promote their production (payment for ecosystem services) **O7.2-A5** Mobilize researching and training (local innovation system)
O7.3 Set up certification systems that recognize certain ecosystem services	**O7.3-A1** Promote dialogue between sectors **O7.3-A2** Set up procedures for recognition (charters, labels, etc.) of ecosystem services
O7.4 Manage biodiversity and resources at the territorial scale	**O7.4-A1** Define the receptive capacity of territories (ecological integrity) **O7.4-A2** Align scales of regulation with scales of management of biodiversity and resources (infrastructure, corridors, minimum surface areas, etc.) **O7.4-A3** Coordinate activities within territories: integrated and concerted management
O7.5 Set up adapted information systems to facilitate monitoring of implementation of ecological intensification	**O7.5-A1** Construct or co-construct indicators of ecological intensification **O7.5-A2** Set up checklists of actions and indicators for each objective **O7.5-A3** Include assessments and indicators for monitoring ecological intensification of aquaculture systems in territorial projects and observatories

CHAPTER 7. HOW TO MEASURE EFFECTS OF ECOLOGICAL INTENSIFICATION?

Measurement of the results and effects of ecological intensification of aquaculture then assumes, like all innovations or policies, whether of a sector or territory, having assessment tools of results and effects. To do this, we propose a few methodological pathways for setting up appropriate indicators, as well as a general checklist in line with the examples of actions shown previously (§ 6). We will describe the following:

(1) how and why to co-construct these indicators (§ 71)

(2) the importance of monitoring experiments (§ 72)

(3) examples of indicators for the actions at the farm scale (§ 73)

(4) examples of indicators acting at the scale of sectors and/or territories (§ 74).

71. CONSTRUCTION OR CO-CONSTRUCTION OF INDICATORS: PRINCIPLES AND INTEREST

Indicators have many functions: measurement, communication, awareness, or social norms. This variety leads to considering systems of indicators and information as both technical and social systems that result from a social construct and a trade-off at a given moment. Measurement of the sustainability of aquaculture farms as well as their contribution to the sustainability of the territories in which they are located has been an occasion to study the roles and functions of indicators (Rey-Valette *et al.*, 2008; 2010) and to advocate for a participative approach of co-construction of indicators as a function of the principles and values to which they refer. **Approaches for co-construction of indicators that promote learning and adoption of actions and policies to which they refer.**

It is thus recommended, after approaches to co-construct scenarios and actions, to follow the rationale of co-construction for indicators of ecological intensification. It is in fact possible to organize discussion groups around monitoring of ecological intensification from the examples provided by the guide. It consists of keeping a reference to the logical framework by proposing to participants that they select and rank them as a function of the context, objectives, sub-objectives, actions, and indicators so as to be able to follow the effects of the changes envisioned. However, the choice of indicators must also consider the state of existing information systems and conditions for collecting non-existent information. It is essential to not repeat or multiply measurement and assessment procedures. This knowledge about available information assumes having certain skills. It is thus also possible not to need co-construction to develop indicators and to construct a system of monitoring and information afterwards for the objectives and actions that were co-constructed. Construction of indicators is thus the result of participants in the approach, with the support of a few researchers from diverse disciplines and a few diverse specialists in ecological intensification and information systems.

72. SETTING UP MONITORING OF EXPERIMENTS

It consists of monitoring at an overall scale, for a set of farms within a territory, the changes observed in interactions within networks of actors and institutional systems and forms of coordination, or even market creation. At the same time, it is important, at the scale of the units involved in experiments, to propose experiment-monitoring sheets to identify and measure the changes. These changes may involve production, quality, quantity, type of work requested and organization within the farm, costs and cost-savings, and of course, the types of difficulties encountered. A technical sheet can be accompanied by photographs to document changes over time.

73. PROPOSAL OF INDICATORS AT THE FARM SCALE

We propose here a non-exhaustive list of potential indicators as a function of sub-objectives, given that decisions will need to be made as a function of the state of already-existing information systems, so as not to weigh down information collection too much and ensure feasibility of the monitoring system, especially its long-term viability. The examples furnished here constitute simple proposals that need to be supplemented and adapted, given that the final number of indicators must not be too large.

O1. Minimize dependence on external resources

Sub-objectives	Examples of indicators
O1.1 Promote use of inputs from non-human sources	Number of species per trophic level Proportion of production in each trophic level Percentage of feed ingredients of marine origin in the ration Biomass produced per species per kg of feed (feed efficiency) Energy used per kg of product Fossil energy used per kg of product Quantity of chemical inputs (medicines, pesticides) used per kg of fish produced Emergy indicators: ELR, EYR, %R (see Sidebar no. 25)
O1.2 Use natural or local resources as inputs as well as ecosystem functions	% of alternative treatments (without synthetic products) out of all treatments Percentage of endogenous feed Integration with terrestrial or aquatic production Biomass produced per species per kg of feed (feed efficiency) Number of different species raised in polyculture Number of contracts with farmers for collection of sludge Presence and percentage of allochthonous species and associated risk levels Percentage of allochthonous species out of total production

O2. Increase performance of aquaculture production systems and product quality

Sub-objectives	Examples of indicators
O2.1 Facilitate/encourage biotechnical changes that promote an increase in farm economic performance	Number of compartments of animal or crop production on the farm Variation in the gross margin Number of work stoppages or accidents per year Percentage of hours of work stoppage out of all hours worked Work productivity (tons/worker) Quantity of work used (number of workers X hours) per ton of product Percentage variation in the feed-conversion ratio Biomass produced per species per kg of feed (feed efficiency)
O2.2 Increase and better use the quality of products: nutritional, flavor, health, and ease of processing	Presence of production charters Difference in sales price / mean market price Presence of a quality test of products Certification procedures obtained Percentage of the production labeled
O2.3 Reduce waste	Biomass produced per species per kg of feed (feed efficiency) Water quality out of the animal-production system (especially percentage of nitrogen and phosphorus products in suspended matter) Indicator of efficiency of nitrogen imported into the system Waste in suspended matter, nitrogen and phosphorus products especially in water out of the animal-production system (kg/kg feed) Variation in the gross margin
O2.4 Develop a culture of assessment and monitoring	Presence of tools for monitoring techniques and finances of the fish farmer Use of accounting Presence of a notebook to record farm performances Number of work hours per year to monitor water and product quality Number of work hours to monitor performance of animal-production processes per ton of product

O3. Improve robustness, flexibility, and resilience of systems via integration and functional complementarity

Sub-objectives	Examples of indicators
O3.1 Better use synergies: species, habitats, functions, services, practices, etc. so as to optimize use of trophic levels and habitats	Number of species per trophic level Proportion of products from each trophic level Number of hours for activities to maintain habitats or protect autochthonous species (flora and fauna) Number and nature of activities to maintain habitats or protect autochthonous species (flora and fauna) Presence/absence of plant formations at the edges of production systems or properties
O3.2 Strengthen the adaptation capacity of aquaculture systems	Survival rate Number of health treatments Levels of biological indicators of environmental quality (NGBI (*), BIRM (**), BID (***), IRF (****)) Morphological indicators of watercourses (flow, mixing, etc.) Year-to-year variation in total production and that of each species Variation in the gross margin
O3.3 Decrease environmental impacts of the aquaculture system	Number of species per trophic level Proportion of products from each trophic level Biodiversity measurements: species richness (number of birds, plants, etc.) Levels of biological indicators of environmental quality (NGBI (*), BIRM (**), BID (***), IRF (****)) Visitation frequency of habitats by humans (disturbance) and/or seasonal calendar of practices Measurement of hydrological regimes Frequency of hydrological accidents (floods, dry periods) Ratio of flow of organic matter to quantities of feed distributed Water quality out of the animal-production system (especially percentage of nitrogen and phosphorus products in suspended matter) Concentration of xenobiotics LCA impact categories (eutrophication, acidification, etc.) (Sidebar no. 23)
O3.4 Promote the capacity for resilience of receiving ecosystems	Biodiversity measurements: species richness (number of birds, plants, etc.) Presence/absence of species or habitats with heritage value Presence/absence of plant formations at the edges of production systems or properties Number of species raised of different trophic levels Mass (kg) of products produced/grown using fish-farm waste Presence of independent treatment systems Ratio of the production to the purifying capacity of the receiving environment Dilution index Measurement of hydrological regimes
O3.5 Stop risks of escape of at-risk species	Percentage of allochthonous species out of total production Presence/absence of invasive or undesirable species Escape rate: number of escaped fish / number of fish produced Rate of genetic inbreeding

(*) Normalized global biological indicator, (**) Biological indicator of river macrophytes, (***) Biological indicator of diatoms, (****) Index of river fish.

O4. Diversify market-oriented ecosystem services of aquaculture systems	
Sub-objectives	**Examples of indicators**
O4.1 Diversify production practices (on the same site)	Number of distinct sets of production practices on the farm
O4.2 Diversify products by developing market-oriented cultural services (leisure)	Number of visitors per year Number of school visits Number and types of recreation services offered Number of fish farms having a fishing route Number of fish farms having expensive reception activities Percentage of revenue from leisure activities out of total revenue Year in which reception activities began Cost of arrangements to host visitors
O4.3 Diversify products by valorizing co-products	Number of co-products sold by the farm Percentage of revenue from selling co-products out of total revenue Quantity (or percentage) of sludge exported Distance to sites where sludge is used
O4.4 Diversify markets	Number of products sold by the farm Number of products sold besides fish for consumption Percentage of revenue from selling processed products out of total revenue Percentage of income outside of fish sales Type of distribution chains (% direct local markets, traditional markets, wholesalers, exported, etc.)

74. PROPOSAL OF INDICATORS AT THE SCALES OF SECTORS AND TERRITORIES

O5. Promote recognition of services and better use of skills and know-how	
Sub-objectives	**Examples of indicators**
O5.1 Identify and valorize the services associated with territories	Existence of assessment of services rendered at the territorial scale Existence of a development strategy for non-market services Existence of incentives to use services Existence of surveys about perceptions of populations and stakeholders Number of awareness activities performed with populations and stakeholders
O5.2 Use and adapt traditional know-how to develop practices better suited to territories	Number of days of training taken by fish farmers per year Number of training events or awareness activities performed with fish farmers Existence of adapted technical guides or sheets Existence of extension agents and information meetings Organization of professional networks
O5.3 Use information systems, spatialize services, and adapt territorial assessments used to support territorial planning	Consideration of services in territorial information systems Development of a system of spatialized indicators quantifying the presence of ecosystem services in the zone and interactions with aquaculture systems
O5.4 Improve the eco-innovation capacity of fish farmers and other stakeholders of the territory	Number of days of training taken by fish farmers per year Number of training events or awareness activities performed Existence of extension agents and information meetings Organization of professional networks Existence of adapted technical guides or sheets Adapted offers of financing Percentage of specific financing to research aquaculture innovation out of total financing (e.g., research tax credit)

O6. Improve territorial integration of aquaculture systems by promoting production of non-market ecosystem services

Sub-objectives	Examples of indicators
O6.1 Manage competition between supply services and other services in the territory and between territories	Existence of assessment of services rendered at the territorial scale Existence of a development strategy for non-market services Representation of fish farmers in groups for territorial organization at multiple scales (% of participants) Number of professional/research/manager meetings per year
O6.2 Develop supporting ecosystem services that promote biodiversity	Biodiversity measurements: species richness (number of birds, plants, etc.) Presence/absence of species or habitats with heritage value Existence of charters of landscape insertion Number of awareness activities about services rendered by aquaculture in the territory Respect for the loading capacity of the receiving environment Quality of the receiving environment (NGBI (*), BIRM (**), BID (***), IRF (****), etc.) Surface area of farms in green corridors and spaces Surface area of plant zones around the pond Number of contracts of financial incentives for practices that respect biodiversity
O6.3 Develop regulating ecosystem services	Water quality out of the farm Existence of incentives for hydraulic management of farms Percentage of the surface area and perimeter of ponds with vegetation Ratio of surface area to perimeter of waterbodies (Index of shoreline development) Number of inhabitants close to farms benefitting from protection from floods and storms
O6.4 Develop cultural ecosystem services and the attractiveness of territories	Number of activities of tourist use of aquaculture systems Number and type of recreation services offered Number of fish farms having a fishing route Number of fish farms having expensive reception activities Ratio off the surface area under water to the total territory surface area (lake index) Index of the % of the territory concerned by fish farming (landscape) Number of reception installations near aquaculture zones Existence of specific signage Existence of museums, organizations, or expositions about aquaculture systems and number of people visiting per year Number of people visiting farms per year Number of collective events devoted to aquaculture activities or their products

(*) Normalized global biological indicator, (**) Biological indicator of river macrophytes, (***) Biological indicator of diatoms, (****) Index of river fish.

O7. Adapt mechanisms and instruments of territorial governance and help stakeholders participate

Sub-objectives	Examples of indicators
O7.1 Promote participation in systems of territorial governance	Representation of fish farmers in groups for territorial organization at multiple scales (% of participants) Number of professional/research/manager meetings per year Existence of professional organizations Rate of membership in professional organizations
O7.2 Identify and assess the services associated with territories with local actors	Existence of assessment of services rendered at the territorial scale Existence of a development strategy for non-market services Existence of surveys about perceptions of populations and stakeholders Consideration of services in territorial information systems
O7.3 Set up certification systems that recognize certain ecosystem services	Existence of incentives to use services Existence of charters or labels valorizing ecological intensification and rendered services Rate of membership of farms in labels that use ecological intensification and rendered services
O7.4 Manage biodiversity and resources at the territorial scale	Existence of incentives to use services Surface area of aquaculture systems integrated into green and blue spaces Percentage of the territory involved in biodiversity conservation measures (Natural Parks, Ramsar or Natura 2000 zones, sensitive natural spaces, etc.) Percentage of aquaculture systems involved in biodiversity conservation measures (Natural Parks, Ramsar or Natura 2000 zones, sensitive natural spaces, etc.)
O7.5 Set up adapted information systems to facilitate monitoring of implementation of ecological intensification	Consideration of services in territorial information systems Development of a system of spatialized indicators quantifying the presence of ecosystem services in the zone and interactions with aquaculture systems Number of technical guides and sheets Existence of networks for sharing experiences about ecological intensification and number of participants in them Existence of an adapted system of indicators Existence of means or supports to communicate/disseminate results

CHAPTER 8. REFLEXIVE RESULTS OF A FEW EXPERIMENTS

Finally, we present a few concrete applications of principles of ecological intensification to sites studied in the PISCEnLIT project:

(1) intensive production of panga in (§ 81)

(2) production of carp in France (§ 82)

(3) systems of integrated fish farming in Brazil (§ 83)

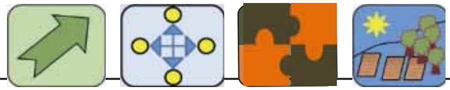
(4) intensive production of salmon in recirculating circuits (§ 84)

81. ECOLOGICAL INTENSIFICATION IN THE TROPICS: INTENSIVE PANGA PRODUCTION IN FRESHWATER IN SUMATRA (INDONESIA)

811. Summary of the previous animal-production system

Ponds for aquaculture production were recently organized in the region of Jambi in Sumatra in response to the desire of actors to diversity agricultural production. These ponds fill from groundwater and accumulate rainwater without water renewal. At the end of the cycle, emptying is performed by pumping and creates effluents of sludge and nutrient-rich water. The stocking rate is 2000-3000 panga (*Pangasianodon hypophthalmus*) per pond, with two production cycles per year, which grows 5 g juveniles into 600 g fish (on average) in six months. Production is performed with ad libitum artificial feed, which represents most (>80%) of the production cost.

812. Scenarios of ecological intensification implemented



Improving fish production yields without increasing inputs (Objective O2.)

Diversifying products (polyculture of fish and market crops) (Objectives O2., O4. and O3.)

Partial purification of water by plant biomass (Objectives O2. and O6.)

Recycling of effluents as fertilizers for agricultural production (Objectives O2. and O6.)

813. Methods for implementing scenarios

These scenarios of ecological intensification consisted of confining panga in a cage (5 m X 10 m) in the center of the pond, as shown in the photo above. The free zone of the pond was then stocked with 500 giant gouramis (*Osphronemus goramy*), which is an omnivorous fish that sells for much more than panga (three times as much). Common duckweed (*Lemna minor*) is used to pump dissolved waste elements in the pond from panga production, as well as to feed the gouramis. There was still distribution of compound feed, but it was given only to the panga, based on a feed ration set as a function of fish biomass. At the end of the production cycle, pond water and sludge were recycled to nearby agricultural farms that grew market crops, oil palm, and fruit trees. The gouramis were grown to a marketable weight of 600-800 g in one year, which corresponds to two production cycles of panga.

814. Results observed

The following figure summarizes the magnitude of flows between compartments before and after the experiment. There was an increase in the use of natural resources and functions and a decrease in disservices. The slight increase in inputs compared to the initial situation corresponds to the acquisition of juvenile gouramis at the beginning of the cycle. These changes were accompanied by an increase of both the market production (gouramis) and the ecosystem services produced by the fish farms (use of effluents as fertilizer; market-crop production).

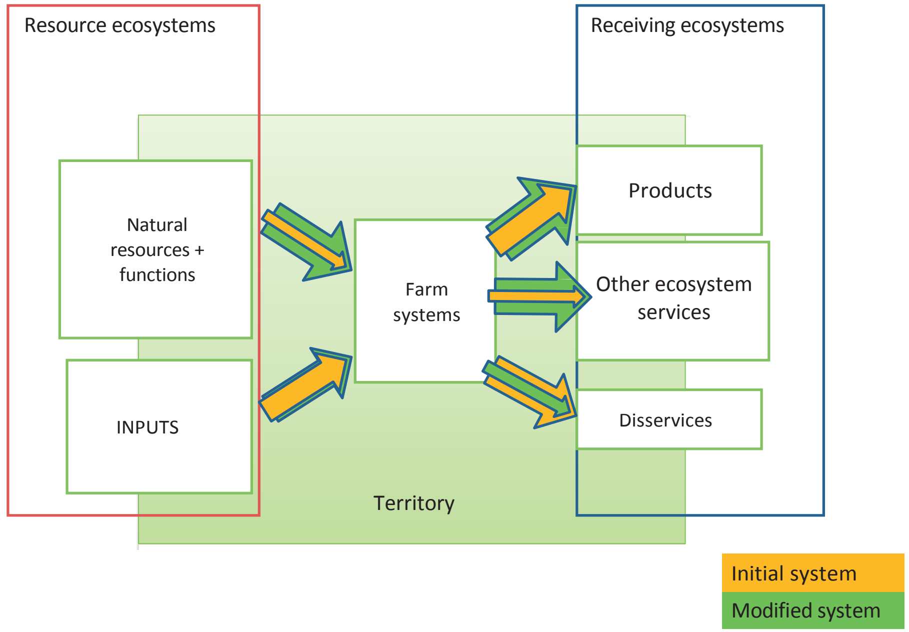


Figure 11: Consequences of the ecological intensification experiment in Indonesia

815. Points of caution

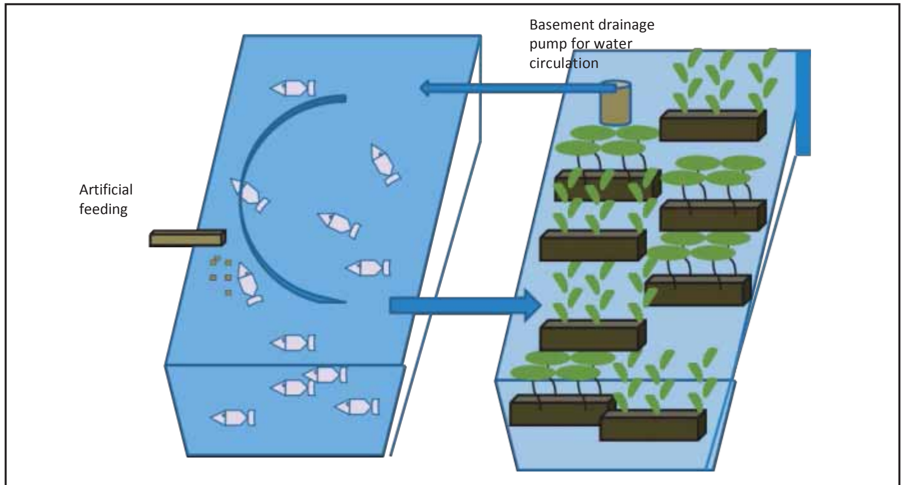
The duckweed is little consumed by the young gouramis, and it is thus necessary to ensure that it does not proliferate at the beginning of the cycle by balancing their growth and their consumption by gouramis. The other point focuses on manipulation of the gouramis. It is a fragile species that must be manipulated carefully and infrequently.

82. ECOLOGICAL INTENSIFICATION IN FRANCE: CARP PRODUCTION

821. Summary of the previous animal-production system

Carp (*Cyprinus carpio*) is one of the main pond species raised in France, essentially in extensive ponds. The production cycle lasts about 3 years. Carps are raised in polyculture with whitefish (roach, rudd, etc.) and a few carnivorous fish (pike, perch, zander). The polyculture benefits from the trophic chain in the pond, which can be stimulated by addition of mineral organic fertilizers (slurry, manure). One possible pathway for development for carp production is intensive production in small ponds fed by granulated feed, which would increase fish growth.

822. Scenarios of ecological intensification implemented



Setting up intensive animal production fed with an artificial feed (Objective O2.)
Closing the water circuit with a lagoon pond planted with autochthonous or ornamental aquatic plant species to purify the water (Objective O3.)
Installing a new ecosystem (Objective O6.)
Offering supplemental revenue sources (Objective O4.)

823. Methods for implementing scenarios

The experiment, performed in earthen ponds of 500 m^2 (in duplicate), examined three animal-production conditions starting from 20 g carps: extensive (3 individuals per 4 m^2) and unfed, intensive (8 individuals per 4 m^2) fed, and intensive closed with a lagoon-pond of the same size with plants. In each stock pond were added 50 roach and 2 tench to increase use of plankton biomass. Three hundred autochthonous plants were planted in the lagoon-ponds: mints, cattails, mannagrass, water lilies, hornworts, canarygrasses.

824. Results observed

Despite problems with high mortality at the beginning of the experiment (in all ponds) due to the poor quality of carp, the "fed" intensive ponds had higher production (2.3 times has high) than extensive ponds and did not differ from that of intensive ponds. Water quality measurements in the ponds show that the combined system had, on average, concentrations of total nitrogen 45% lower than those in the simple intensive system and 20% lower than those in the extensive system. Also, total phosphorus concentrations were 69% lower than those in the intensive system and 56% lower than those in the extensive system.
Assessment of the associated biodiversity in the lagoon-pond remains to be done. This initial experiment is promising and must be continued under better animal-health conditions. It shows the interest in associating fish and plants and, more generally, the interest in combining intensive productive zones with extensive zones responsible for remediation and supporting biodiversity.

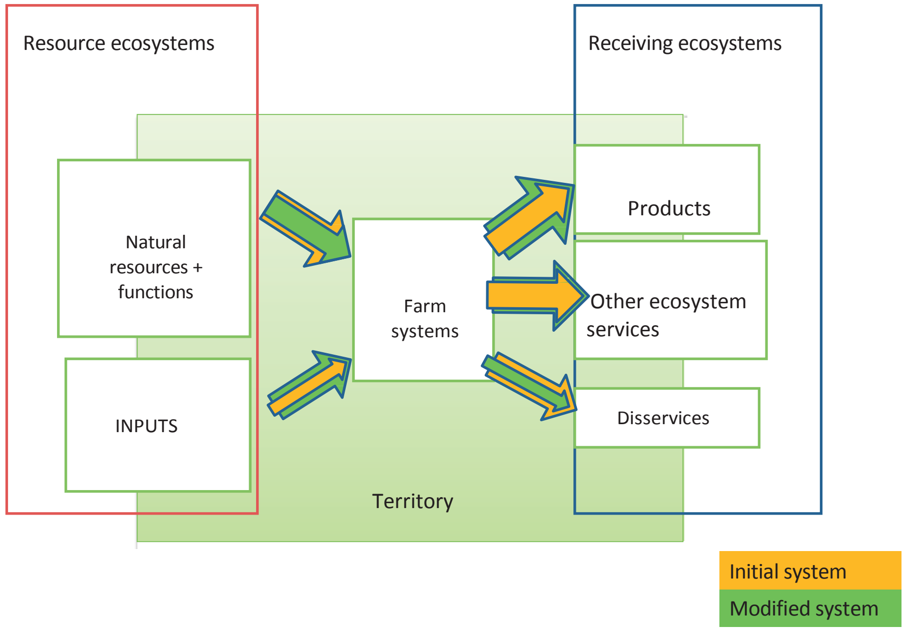


Figure 12: Consequences of ecological intensification of carp production

825. Points of caution

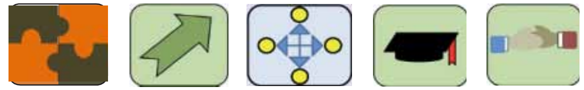
Fish feed is an expensive resource and the feeding tables for carp remain to be validated. Visual monitoring of feed uptake is not simple in ponds; this resource must be used carefully. It would be better to have a feed containing few or no marine ingredients. The quality of carps used for stocking is an important point. Disease risks exist and need to be controlled. Finally, a planted lagoon-pond is not immediately effective. Plants need time to establish themselves before they can effectively use nutrients from fish waste. It is also necessary to think about exporting some of the plants to allow them to regrow and remove dead vegetation at the end of the growing season.

83. ECOLOGICAL INTENSIFICATION OF INTEGRATED FISH FARMING: PRODUCTION OF PIGS/FISH IN CHAPÉCO (BRAZIL)

831. Summary of the previous animal-production system

In the region of Chapéco, pond construction dates to the 1980s. Their main objective was to serve as water reserves. Most of these ponds were constructed by diverting watercourses; thus, they are near rivers. The 2012 Forest Code established 30-m-wide protection zones (*Area de Preservaçao Permanente*, APP) along watercourses at least 10 m wide. Consequently, fish farms in this region no longer conform to the APP regulations. The ponds are part of farms (average size 50 ha) in which crop and animal production are the main activities. After having systems that integrated fish production (tilapia, common carp, bighead carp) with pig production on medium-sized ponds (0.14-3.5 ha) for about 10 years, fish farmers in the region returned to non-integrated polyculture/pig production with artificial feed based on compound feed or farm plants. The density was 5000 fish per ha, with a production cycle of 11 months. Ponds were filled from rainwater and pumping of groundwater. Production per cycle varied from 4-6 tons per ha. Most of it was sold at local markets. The main difficulty for these producers in their non-conformity with the APP regulation; consequently, the experiments in the project aimed to reveal the water-regulating services that the ponds and fish-production systems provide. These services act not only on water storage but also water quality and, more generally, on biodiversity maintenance.

832. Scenarios of ecological intensification implemented



Partial purification of water by plant biomass (Objective O3.)

Diversifying products. Producing biomass and compost (Objectives O2 and O4.)

Improving fish-production yields without increasing inputs (Objective O2.)

Promoting social and political acceptance of fish farming in the region (Objective O5.)

Improving resilience of systems (Objective O3.) and territories (Objective O7.)

833. Methods for implementing scenarios

The proposed ecological intensification scenario aims to reconcile fish farming with the APP regulation and improve the image of fish farming to the local population and, more generally, to contribute to the dynamics of local development by promoting the use of local resources (ponds) and know-how. Once presented to fish farmers, this "purification of waste water" scenario was the focus of experiments in four different situations. It consisted of building a treatment lagoon of water covered by water cabbage (*Pistia stratiotes*). The first ponds were dug. Samples to monitor water quality were taken from several points: in the pond, in the purification lagoon, at the outflow of the pond, and upstream in the river. In addition, it is planned to perform compost experiments with water cabbage that will be regularly removed from purification lagoons. Meetings to present the results have been organized.

834. Results observed

There was an increase in use of natural resources and functions and a decrease in disservices. These changes were accompanied by a slight increase in market production (fish, compost) and ecosystem services (water quality).

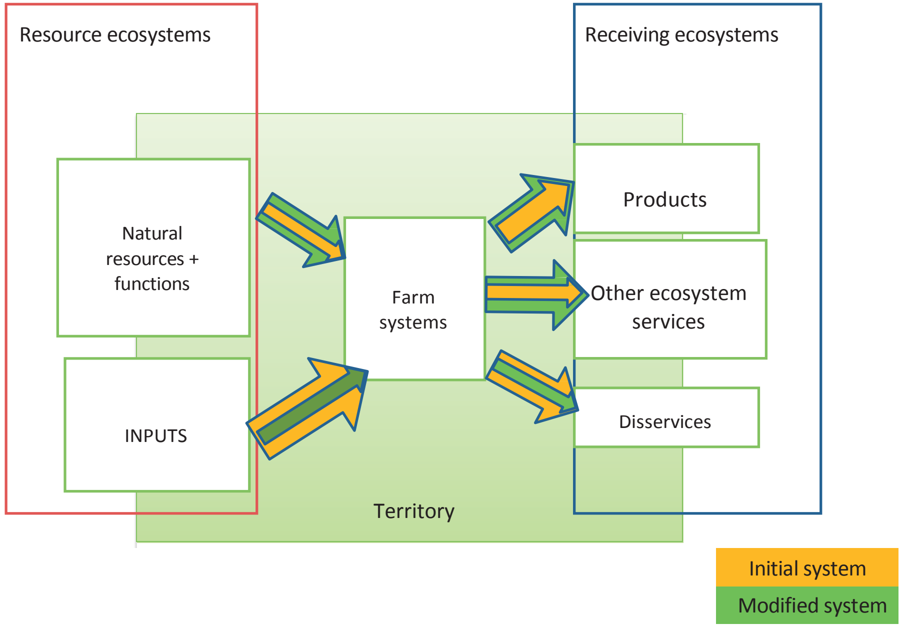


Figure 13: Consequences of ecological intensification at Chapéco, Brazil

835. Points of caution

Because water cabbage grows quickly, it is necessary to maintain a good density in the lagoon and keep plants from overflowing it.

84. ECOLOGICAL INTENSIFICATION OF A RECIRCULATING SYSTEM: INTENSIVE SALMON PRODUCTION IN NORMANDY (FRANCE)

841. Summary of the recirculating system

In a general context of decreasing water resources and regulations limiting emission of waste into the environment (European Union Water Framework Directive), recirculating animal-production systems offer the possibility to decrease water consumption, manage water quality during production, reduce the amount water emitted, and treat this water (in lagoons or marshes) (Sidebar no. 3). The case studied is a company producing Atlantic salmon (*Salmo salar*) in Normandy near the Bay des Veys. In 2013, the company had 2 tanks 5 m deep and 15 m in diameter. Water is pumped from a depth of 15 m, which gives it a certain thermal inertia (16°C in summer and 10°C in winter). A current is generated in the tanks and causes the salmon to actively swim. After a cycle of 12-15 months, production is 50 tons of salmon per tank (i.e., 120 kg per m^3). total production was 80 tons in 2013, and the objective is to produce 240 tons in 2015. Sludge is stocked in a decanting tank and used as a fertilizer (maize, wheat, and rapeseed crops nearby). Outflowing water is emitted into polders, where it naturally purifies before returning to the sea. The salmon are sold in France and destined for high-end restaurants and traditional fishmongers.

842. Scenarios of ecological intensification implemented

- Automating fishing and optimizing the recirculating system to decrease use of pumped seawater and energy (Objectives O1. and O2.)
- Recruiting a new employee to decrease individual workloads (Objective O2.)
- Purification by lagoons with high algal yields (sea lettuce) and creating a marsh (Objectives O2., O3. and O6.)
- Recycling sludge (Objectives O2. and O3.)
- Certification and developing direct sales (Objectives O2., O3. and O4.)
- Developing links with research and hosting school groups and tourists (Objectives O5. and O6.)
- Modifying the building to improve its fit into the landscape (Objective O6.)

843. Methods for implementing scenarios

Since the company was created recently, not all options have been implemented yet. It has close links with researching and training organizations. Thus, experiments to test the sensitivity of the results were performed in parallel at the IFREMER station in Palavas. In this framework, the following were analyzed in particular: effect of N:P ratios on water-cabbage growth, (ii) comparative effects of NH_4^+ (open system) and NO_3 (recirculating system) on water-cabbage growth, and (iii) flows of nutrients and CO_2 in a lagoon system with high algal yield.

Installation of a planted marsh is planned to treat water coming out of the water cabbage pond and the sludge decantation pond and to create habitats that promote support services and biodiversity. The company also wishes to offer cultural services by hosting visits by schools groups and tourists and helping to set up a Regional Aquaculture Center (multi-sector). Finally, development of direct sales at 30% will eventually improve visits and diversify markets.

844. Results observed

This type of intensification via co-production of sea cabbage and treatment of waste by constructed marshes helps decrease disservices caused by waste. The nitrate concentration at the input of the algae crop is 25 mg L^{-1}, and the algae decrease it by 20-30%. This systems treats water at minimal cost, given that algae production could be increased by using CO_2 coming from degassing of the recirculating system. There is still no market for sea cabbage, but ways to add value to it are envisioned (high-quality food additive, fresh algae). The sludge is already used as a fertilizer by a nearby farmer.

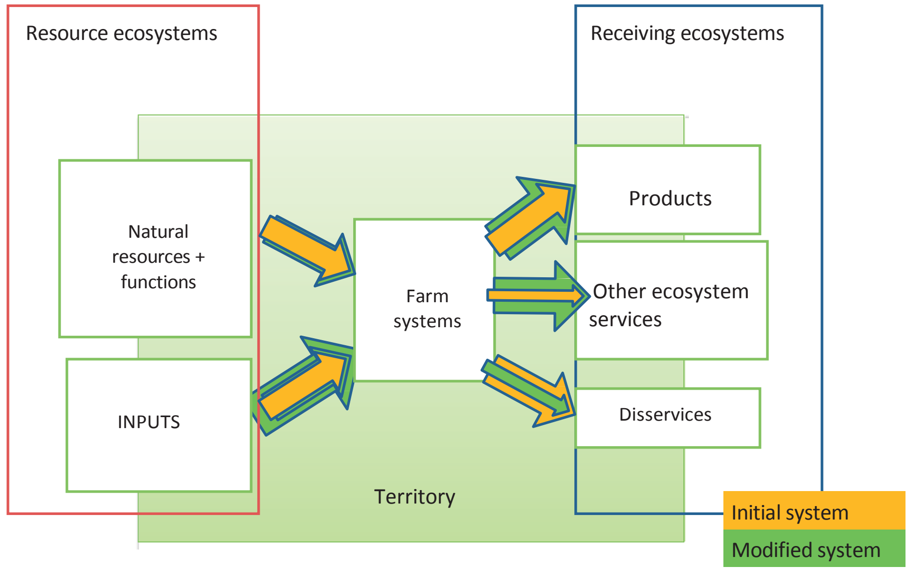


Figure 14: Consequences of ecological intensification of fish production in a recirculating system

845. Points of caution

Potential obstacles include costs associated with installing and/or maintaining the lagoons with high algal yield and the constructed marsh, whose size is difficult to optimize. The planned options require additional employees, especially to monitor and harvest water cabbage and sell products directly on-site. Analyses of the quality of sludge and water returned to the see are paid for by the manager.

CHAPTER 9 . CONDITIONS, LIMITS, AND RECOMMENDATIONS FOR ECOLOGICALLY INTENSIVE AQUACULTURE

The future of aquaculture will be faced both with strong pressure to develop and increasing limits, which will require **rethinking relations between aquaculture systems and ecosystems for better territorial integration**. Ecological intensification, until now developed main in agriculture, **offers promising perspectives for diversifying pathways that can strengthen the sustainability of aquaculture. It assumes implementing eco-innovation processes that involved not only know-how and biological and ecological functions but also adapted sociological and institutional conditions**. Design and adoption of these new practices of “renaturalization” of systems (Stassart *et al.*, 2012) implies jointly changing rationales and values at different levels: (i) in the management of aquaculture farms, (ii) in the organization of supply chains and professional groups and, even wider, (iii) in systems for planning and organizing territories.

We did not want to provide a predefined reference model here, but on the contrary, to propose **exploring different pathways** as a function of contexts or former practices **by considering a variety of complementary objectives.** It is by progressively integrating successful experiments and implementing a set of practices around this issue that the definition of ecological intensification will progressively be co-constructed and put into operation. To accompany this process, from scientific knowledge and practices observed in different study sites, **this guide furnishes, for each type of objective, checklists with examples of actions and indicators. From these elements, it becomes possible to co-construct scenarios of ecological intensification adapted to each aquaculture system**

With publication of this work, we wish the following:

(1) emphasize, in a reflexive attitude, a few key points regarding the conditions and limits of ecological intensification for aquaculture (§ 91)

(2) propose a few recommendations as a function of the main principles of implementing sustainable development policies (§ 92)

91. CONDITIONS AND LIMITS OF ECOLOGICAL INTENSIFICATION OF AQUACULTURE

911. Proactive or progressive support by producers and stakeholders

The PISCEnLIT project allowed for both exploration of the theoretical and scientific foundations of ecological intensification and discussion of this concept with partners in professional organizations, managers, and fish farmers. The two following situations were encounter most often:

(1) Proactive support by certain partners and producers, some of whom had already experimented to some extent with some of the proposed scenarios. This was the case, for example, of the combined production systems, which led to a few trials in Lorraine and Brenne. In this situation, formalizing the ecological intensification approach, besides strengthening the legitimacy of these practices for stakeholders, had provide a double interest by (i) showing the need to adopt a system and territorial rationale when formalizing ecosystem services and (ii) highlighting the sociological and institutional limits to generalizing these practices. In Brazil, the formalization of existing practices in an overall reference system promoted a change in viewpoint of the administration in favor of aquaculture.

(2) Situations in which partners had no knowledge of the concept of ecological intensification and in which it was necessary to have a progressive and adaptive approach. It helped to accompany this approach with training and awareness sessions, not only with producers but also with actors in the supply chain and the territory. Once the principles of ecological intensification were explained, these processes attracted the attention of certain productions, who, for example in Indonesia, paid for most of the second phase of experiments themselves.

Regardless of the situation, adoption of the concept involves concerted efforts that depend on conditions for adopting innovations but also processes of collective engagement and recruitment that need to be progressive and self-reinforcing (Aoki, 2006).

912. Conditions of and limits to collective adoption of the process

We identified many potential limits, which are useful to list so as to be able to anticipate and address them. The diversity of profiles and rationales of farms in the same territory represents a limitation to implementation of this new reference system, which requires a collective approach, even if a diversity of technical options can be kept. We were able to show that it is especially differences in eco-innovation capacity related to age, status, and ecological awareness that explain the degree to which producers are open to general implementation of these practices.

The essential of having a procedural approach, in the sense of an "iterative and adaptive approach" (Clément and Madec, 2006), is reinforced by the complexity of the natural processes and functions that are used. Consequently, ecological intensification requires a fine-tuned global approach, which assumes a period of specific adaptation and learning to master it.

The complexity of interactions between factors gives rise to a paradox: consideration of ecological functions and greater integration with natural environments strengthens the long-term robustness and resilience of aquaculture systems, but this integration with the environment may increase short-term risks due to variability in environmental and climatic conditions. **Consequently, it is essential to diversify trials and reinforce actor capacities and, more generally, aquaculture systems in terms of collection learning and anticipation by adapted monitoring.** In addition, the characteristics of eco-innovations to which ecological belong implies favorable institutional conditions at the supply-chain and territorial scales. We highlight this institutional dimension, especially by distinguishing objectives that fall under individual decisions at the farm scale from those that involve collective decisions at the territorial scale.

913. Institutional synergies with beneficial consequences

Like for ecosystem approaches for fisheries (Young *et al.*, 2010), **ecological intensification must be considered by searching for synergies with other structuring reference systems.** It is useful to organize ecological intensification activities with policies and measures in favor of sustainable development and biodiversity conservation but also with measures in favor of sustainable means of existence, maintenance of family production systems, and, more generally, to relate them to policies for adaptation to climate change. **In all cases, it consists of integrated approaches involving integrated approaches involved learning and requiring essential and interactive measures of information and awareness.** It also consists of going beyond the farm scale by pondering synergies between upstream and downstream compartments and especially by facilitating reinterpretation of interactions between actors in production supply chains. Changes in the use of co-products and waste can encourage resistance by suppliers or make them change toward service and advice activities by taking up the perspectives offered by ecological engineering and industrial ecology. More generally, these circular interactions will lead to new closeness (Torre and Zuindeau, 2009), which could lead to defining, based on positive externalities observed in territorial economies (Courlet *et al.,* 2013), "ecological clusters" to strengthen the co-production of ecosystem services.

914. New relations with consumers and society

Ecological intensification can be included, according to Griffon (2013b), to the seventh agricultural technological revolution, which aims to produce more while respecting the environment. It comes from social conflicts, especially between environmentalists and actors of the agricultural world. This new revolution brings about changes that lead to increasing distance from conventional agriculture (fish farming) and a renewal of confidence by consumers. The institutionalization process of this new form of production proceeds as much "from above" via legislation as "from below" via development of initiatives from the rural environment (Van Dam *et al.*, 2012). Conventional agriculture has had the effect of extracting products from their socio-political context (Audet and Gendron, 2012). This had led to abandonment of ecological functions of soils and biodiversity. **Ecological intensification offers to re-embed production by basing it on improving their integration with ecosystems and territories.** Products from fish production are goods that come from confidence: that is, the consumer can only be assured about characteristics of the good consumed via advice from an expert (Salladarré *et al.,* 2013). This type of good requires information about production methods that can only be delivered by a direct link of confidence with the producer or an ecolabel. The demand for ecolabels is greater for goods of confidence than for other types of goods (Bonroy and Constantatos (2004), cited by Salladarré *et al.* (2013)). This demand will be that much greater if consumers prefer responsible behaviors from an ecological

conscience. **It consists of building a new social and environmental contract (Griffon, 2013b) that will need to be applied in a concerted** manner with fish farmers and crop farmers to face challenges of food security, the struggle against poverty, and adaptation to climate change.

915. New perspectives for interdisciplinary research

This exploratory research on ecological intensification of aquaculture systems identified many interesting research pathways beyond those often explored of ecological interactions, remediation processes, and ecological restoration. In agriculture, this ecological intensification, usually focused at the decision scale of one farm or groups of farms, often led to focusing research on motivations and advantages of rural agriculture so as to reconcile the environmental dimension and the main ethics of this movement (Griffon, 2013a). For aquaculture systems, this research followed a program about co-construction of sustainability indicators of aquaculture systems (Rey-Valette *et al.,* 2008), which allowed it to benefit from important interdisciplinary results, especially the recognition of the contribution of aquaculture to the sustainability of territories and the necessary adaptation of sector and territorial governance organizations. This awareness can indeed take time and implies an interdisciplinary dialogue to construct a common representation of the concept of an aquatic ecosystem. The latter represents both an intermediary object (Vinck, 2000) for the dynamics of interactions and a research result.

This territorial dimension redefines the frontiers of research and raises questions about concepts such as ecological solidarity between territories or landscapes (De Groot *et al.,* 2010). The concept of landscape carries an ecological dimension in which it implies thinking about continuities and discontinuities as well as geomorphological forms, but also in social sciences, in which the landscape constitutes a social construct and a heritage resource (Burel and Baudry, 1999). **We also understood territorial interactions via specific assessment tools such as life cycle assessment, with new extensions that were performed with social life cycle assessment (Mathé, 2014).** However, for this field, our work encountered large problems of representativeness and availability of data. Generalization of these approaches to social sciences nonetheless offers interesting research perspectives to compare activities or supply chains (Macobe, 2013b). Likewise, the PISCEnLIT project was the occasion to **extend these approaches by associating and organizing them successfully with Emergy indicators (Wilfart et al., 2012).** Nonetheless, despite these promising perspectives, these approaches have difficulty integrating ecosystem services in the indicators used, which thus remain still too greatly focused on companies and supply chains. Likewise, other types of indictors could also have been developed at finer scales, corresponding to elementary production units (tanks, ponds), which also constitute elementary units of the human-created landscape.

Among the possible extensions in the mid-term**, it is necessary to continue reflecting on indicators** that can assess and direct implementation of ecological intensification. In particular, it is a matter of co-constructing, at the end of experiments, a few keystone indicators suitable for monitoring and comparing results and effects generated by ecological intensification at the scale of farms and territories by integrating ecosystem services more widely.

916. From recognition towards institutionalization of services

Our research shows the importance of understanding perceptions of ecosystem services and questioning the factors that influence them. These factors are many, both individual and collective. They can be studied at the population level in terms of acceptability, at the farm level in terms of incentives, and more generally within territories and supply chains in terms of the needs of institutional innovations. **The importance of social recognition of these services constitutes an essential condition**, as Dendoncker and Van Herzele (2012) remind us, emphasizing that "*the loss of ecosystem services inside and outside agro-ecosystems results mainly from the fact that they are not considered in legislation, nor in decisions about territorial planning. This calls for the use of an integrated, multi-ecosystem approach so as to assess the current situation and anticipate expected changes in ecosystem services*". **In this regard, our work has shown the interest in exploring the diversity of representations of these services in support of public decisions, especially to strengthen the acceptability of measures.**

92. RECOMMENDATIONS

It is useful to recall that implementation of ecological intensification, whether for aquaculture or agricultural systems, cannot be a ready-made "recipe" that can be applied to any system. **Just like sustainable development, it involves a set of principles and objectives that must be individually adapted as a function of the systems and objectives of each fish farmer.** Consequently, its implementation requires specific accompaniment at the scale of farms, supply chains, and territories. In this spirit, we thus formulate a few general recommendations about this accompaniment, organized according to the basic principles of sustainable development (CGDD, 2009):

(1) Principle of participation: Ecological intensification of aquaculture systems implies promoting suitable institutional agreements and systems. They will need to facilitate participation in co-construction of scenarios and actions plans so as to strengthen social awareness and recognition of these eco-innovations. Increased interactions must especially be promoted between actors of aquatic ecosystems and territorial managers.

(2) Principle of management: Implementation of ecological intensification requires fine-scale and adaptive management of actions and their organization. Particular attention must be paid to fine-tuning of changes in practices, which implies series of experiments to identify effects of different factors. Interlocking of the scales at which ecosystem services must be managed assumes a multi-level rationale of governance. Finally, the reasoning of resilience behind these new practices implies reviewing the philosophy of profit in favor of adaptive management advocated by work on resilience (Holding, 1978; Gallopin, 2006).

(3) Principle of transversality: Ecological intensification of aquaculture systems assumes understanding actions and interactions at the scale of all components and compartments of aquatic ecosystems, which conforms to the systems-analysis assessment proposed by the guide (i.e., resource ecosystems, systems of farms, receiving ecosystems, and territories).

(4) Principle of assessment: Experiments of implementation of ecological intensification must be monitored and give rise to development and progressive standardization of indicators, jointly considered with indicators of sustainable aquaculture and possibly those used for sustainable development of territories. It consists mainly of promoting support for a culture of assessment on which management of these processes can rely, as well as adapted tools for assessment and monitoring. In addition, work on public policies for management of ecosystem services emphasizes the need for mapping of these services and in that way promoting spatialization of information (Maes *et al.*, 2012).

(5) Principle of continual improvement: Ecological intensification of aquaculture systems requires combining knowledge from traditional know-how, knowledge from experiments, and input from research in many disciplines already associated with aquaculture systems, as well as new approaches in ecology, agro-ecology, and industrial ecology. This knowledge and these skills are most often brought by networks, whose organization needs to be facilitated (Roth, 2008). Ultimately, they must be used in systems that allow for adaptive and multi-level management of the aquaculture systems and territories involved in ecological intensification.

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Guide for implementing ecological intensification of aquaculture systems

The rapid development of aquaculture in the world has offered, depending on the species and territory, examples of “success stories” but has sometimes also led to social or environmental crises. The issue of food security in 2050 requires improving technology and practices while moving toward practices of “sustainable aquaculture”. These changes promote territorial integration and need to be better recognized and mastered. The framework proposed by ecological intensification of agricultural systems offers an opportunity to redefine objectives for aquaculture by promoting ecological mechanisms to maintain or increase production in these systems. It thus consists of diversifying pathways to sustainable aquaculture and promoting the strengthening of ecological functions while considering sociological and governance constraints.

Thus, the objective of this guide, the fruit of an interdisciplinary research project among French, Brazilian, and Indonesian partners, is to propose pathways for implementation of ecological intensification in aquatic ecosystems of aquaculture. To do so, it supplies (i) many potential objectives based on concepts of agro-ecology, ecosystem services, and processes for co-constructing eco-innovations; (ii) assessment tools (indicators); and (iii) examples of experiments in four types of contrasting aquaculture systems.

This guide is addressed to a wide public: representatives of supply chains or aquaculture producers, representatives of territorial governments or administrations, and more generally, all members of NGOs or associations interested in development of aquaculture and/or setting up of integrated territorial projects, but also researchers and students as well as all actors wishing to implement ecological intensification, including outside the field of aquaculture.