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Evaluation of Aquaculture System Sustainability: A Methodology and Comparative Approaches

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1. Introduction

Over the last 30 years, aquaculture has experienced an unprecedented development in global animal production with an average yearly growth rate of over 10% between 1980 and 2000 (FAO, 2009). During the same period, capture fisheries saw their progression gradually grind to a standstill and growth stopped from 1995 (total catch fluctuating between 90 and 95 Mt/year according to the year). The growth of aquaculture, despite its benefits and the fact that it is the only way to meet the increase in demand for sea products, evaluated at 270Mt in 2050 (Chevassus au Louis et Lazard, 2009; Wijkström, 2003), raises a certain number of issues directly related to its sustainable development. Amongst these are issues related to feed for the farmed organisms, to their biological diversity, to the farms' economic sustainability, to the impact of aquaculture development on social equity and to the set of arrangements constituting the sector's governance.

Feed, for example, is currently the subject of significant controversy as shown by the emblematic article of Naylor *et al*. (2000) that exposes the impact on catches of the massive use of fish meal and fish oil in fish and prawn aquaculture and advocates the return to sparser aquaculture systems, directly inspired by traditional Asian systems which use more extensive techniques based on polyculture and fertilisation and where artificial feed is only seen as a potential supplement. This diagnosis, although interesting as it generated much debate, was, however, incomplete and, in fact, inaccurate: by focusing on a single criterion and a single dimension (environmental) of sustainability, the authors were led to make proposals that had no chance of being adopted by the actors. De facto, farming systems have continued to intensify and this has led to a sustained increase in the use of

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fish meal and fish oils. Indeed, the aquaculture sector's consumption of fish meal and oils increased respectively from 2.9Mt to 3.7Mt and from 0.6Mt to 0.8Mt between 2000 and 2008 (Tacon and Metian, 2008). Over and above the issue relating to the use of feed with a high biological value for aquaculture production, Naylor *et al*. (2000) contrast two aquaculture models: the first one, an input-intensive system, in particular as regards fish meal and oils and *a priori* non sustainable, and the second one, classically described as extensive or semi-extensive, considered to be sustainable. This implicit or explicit assimilation of intensive and extensive/semi-extensive systems with models of respectively weak or strong sustainability can be found in many publications from the 1980s and 1990s (Billard, 1980; Edwards et al., 1988; Kautsky et al., 1997; Lazard, 1993; Veverica et Molnar, 1997), and even quite recently (Belton et al., 2009; Delgado et al., 2003; World Bank, 2007). Two other examples of approaches that take into account only one pillar of sustainable development, in the social domain this time, give contradictory results. The first example comes from work on the role of aquaculture as an activity with a **direct** impact on poverty alleviation efforts (Edwards, 1999, 2000) inspired by the analytical framework of sustainable livelihoods in the rural milieu (Carney, 1998). The conclusions and recommendations of this global reflection process which aim to take into account the assets (physical, natural, human, social and financial) of "poor and vulnerable populations" remain for the most part tentative as Edwards (2000) concludes that if aquaculture remains in theory an attractive way to improve the livelihoods of poor populations, "*there is a need to raise awareness of the large potential contribution of aquaculture*". This goal is far from having been attained. The second example comes from a study of coastal aquaculture in brackish lagoons in the Philippines where Irz et al. (2005) highlighted the significant role played in this country by a mostly "capitalist" aquaculture in income redistribution that benefits the poorest directly (salaries) or indirectly (services). These authors therefore recommend that when public policies are implemented, particular attention should be paid to maintaining such social redistribution outcomes, especially when promoting new technologies. These examples show that the real question is to find whether there are specific aquaculture systems that can contribute to poverty reduction in parallel with profit-orientated systems.

A final example is provided by a large-scale project initiated by ICLARM (now Worldfish) in the Philippines at the end of the 1980s ("GIFT Project", Genetically Improved Farmed Tilapia) which aimed to genetically improve the tilapia most frequently used in farming, *Oreochromis niloticus.* According to its promoters, *the overall development objective of the GIFT Project was to increase the quantity and quality of protein consumed in low income rural and urban populations in tropical developing countries in all regions of the world and increase the income of low-income producers. As with future agricultural and aquacultural developments, the objective was to aim for sustainable systems, in harmony with the natural environment, to benefit producers and consumers*. If, for the most part, this project is considered to be successful from biotechnical and micro-economic viewpoints (Dey *et al.*, 2000; Gupta et Acosta, 2004), various analyses show that things are quite different at social (low usage by "poor fish farmers") and environmental levels (risk induced by the introduction of the GIFT strain in the original area of the Nile tilapia) (Lazard, 2009).

It is clear therefore that numerous discussions of aquaculture sustainability are based on a single component of sustainable development. Very little work has been undertaken on a global and comparative basis. The analysis of the main reference frameworks such as codes of conduct, guides of good practice, standards, labels etc. (Boyd et al., 2005, 2008; FAO, 1995; WWF, 2005, 2006, 2007, 2010 among others) and of initiatives for the construction of sustainable development indicators (Caffey et al., 2000; Consensus, 2005; GFCM, 2010; IUCN, 2005) in aquaculture, show that most of them are based on very unbalanced approaches concerning the dimensions of sustainable development that are taken into account. They are also often highly centralised with little reliance on participatory processes (Mathé et al., 2006; Rey-Valette et al., 2007a). This is why the approach suggested in this article is instead designed to cover all the dimensions of sustainability including the traditional pillars (economic, social and environmental) as well as the institutional one (governance). This latter, in particular, gives this approach its original and innovative nature. At once multidisciplinary and participatory, the approach compares several countries and types of aquaculture system and results in a diagnosis and global recommendations.

The objective of this article is to present a global overview of the method used together with the results of the diagnoses that have been made. The results that are discussed are those of the EVAD project (Evaluation of aquaculture system sustainability) carried out from 2005 to 2009, whose objective was to evaluate the sustainability of aquaculture systems. The issue at stake for the EVAD project was to establish a generic method to analyse sustainable development factors and indicators in aquaculture, which would encompass its territorial dimension and actors' perceptions. In order to guarantee its generic character, the method was developed using highly differentiated sites as regards socio-geography, production systems, farming environments and regulatory systems. Over and above the evaluation process, the project also sought to propose two types of sustainable development indicators for aquaculture: simple indicators (qualitative and quantitative) and, for the environmental aspects, synthetic indicators based on life cycle assessments of aquaculture systems.

We begin by presenting the global framework of the approach, followed by the detailed methodology used to establish a generic check-list of sustainability indicators and finally the application of life cycle assessments to the aquaculture systems under study.

2. The rationale underpinning the approach and the different work phases

The process used for the EVAD project is characterised by its transdisciplinary approach (Bürgenmeier, 2004), meaning that, for each phase of the project, it associates very closely not only human and biological sciences but also the stakeholders who are part of the procedural and participatory approach. The approach relies on the **co-construction** of indicators for the sustainable development of aquaculture which then become a tool to drive and legitimate sustainable development (Boulanger, 2007). The co-construction of indicators with broad-based groups of stakeholders makes it possible to initiate a participatory approach and a collective learning process and facilitates the appropriation of sustainable development (Mickwitz et al., 2006; Fraser et al., 2006; Hatchuel, 2000; Hilden et Rosenström, 2008; Rey-Valette et al., 2007b). This co-production also promotes the institutionalisation of the monitoring and the implementation of the indicator system†,

†The indicator system comprises an information system which gathers information in all its forms (oral, written, private, public…) together with the arrangements for the management of this information (for instance, an observatory).

especially as it draws on local actors' knowledge. The approach is based on a systemic approach to sustainability which encompasses the four dimensions of sustainable development including the institutional dimension which is taken into account through the governance processes. Furthermore, the method favours a territorial approach to sustainability in the spirit of local agenda 21s recommended by the Agenda 21 during the Rio Earth Summit (Chapter 28) by combining two complementary scales of approach: the sustainability of farms and of the aquaculture sector (sectoral approach) and the contribution of fish farms to the sustainability of the areas where they are located (territorial approach). Taking the territorial level into account is a first step towards integrating the ecosystem services provided by aquaculture.

3. The areas

Several carefully chosen areas were used to test the genericness of the method (table 1).
These areas were as follows.

	Rural area		Coastal area	
	Low density	High density	Low density	High density
Weak regulation	Ponds Indonesia (Tangkit) Ponds Cameroon		Coastal ponds Philippines	
Strong regulation		Cages Indonesia (Cirata) Raceways Brittany		Cages Mediterranean (France and Cyprus)

Table 1. Position of aquaculture systems under study according to three criteria: environment, regulation and intensification.

3.1 Rainbow trout farming in Brittany (France)

Rainbow trout farming is an intensive farming system based on a high input level and on an increased stocking rate. At present, in Brittany, the number of trout farms is decreasing, farms are being concentrated and the overall production is being reduced due to numerous constraints: environmental constraints, social constraints (farming activity acceptance, product image, etc.), regulatory and economic constraints (input cost variation, competition with salmon, etc.).

3.2 Mediterranean sea bass and sea bream farming

In order to satisfy a strong demand (tourists and indigenous population), the production of aquaculture fish (mainly sea bass and sea bream) started in 1980 and increased by 25 % each year between 1990 and 2000 (the current production is estimated at 200,000 tonnes per year). Current production systems (consisting of sea-based cages or land-based raceways) are in conflict with tourism and other models will have to be developed (Rey-Valette et al., 2007c). Due to recent crises, aquaculture activity has become concentrated as fish farms have been bought by major groups.

3.3 Fish and shrimp farming in coastal ponds in the Philippines

Fish farming plays a major role in the economy of the Philippines and coastal ponds, consisting essentially of extensive milkfish based polyculture, represent around 60 % of the overall aquaculture production. Observing the development dynamics of Philippine aquaculture systems underlines the significant flexibility of extensive systems compared to the economic fragility of intensive fish farms when markets are saturated.

3.4 Small scale fish farming in Indonesia

In Indonesia, although freshwater fish farming is generally a small-scale activity, it nevertheless represents one of the highest yearly production rates in the world. Fish farming production systems with high input rates have rapidly developed locally over the last ten years: catfish in ponds in the Centre of Sumatra (Tangkit, Jambi province) and carps and tilapia in floating cages in the Cirata reservoir (West Java).

3.5 Commercial fish farming in family agricultural enterprises in Western Cameroon

Despite an increasing demand for fish, the history of fish farming in Cameroon (and more largely in Sub-Saharan Africa) remains characterized by a marginal production which is most likely due to the fact that their farming systems are not sufficiently efficient from technical and socioeconomic points of view. The high plateaux in the Western region, which are characterized by a very dynamic diversification of agricultural production systems, represent one of the areas in Cameroon where the greatest number of fish ponds have been constructed with numerous fish farming innovations involving an input intensification.

4. Methodology used to establish the check-list of sustainability indicators

The process of establishing the check-list of sustainability indicators in aquaculture relies on a hierarchical nesting approach which makes it possible to link **indicators** with general sustainability **criteria and principles** (Prabhu et al., 2000). This type of nesting puts into context the definition of indicators and they can then be linked to territorial and sectoral issues. This approach differs from initiatives to construct indicators as inventories linked to pillars of sustainable development and uses instead a principle-guided method, which, through a cross sectional conception of social choice and by putting the general principles of sustainable development into context, helps in its appropriation by actors (Droz et Lavigne, 2006). The relationship between the implementation phases of the Principle Criterion Indicator approach is shown in figure 1. The preparatory phase should establish a diagnosis of the sector and study actors' representations in order to address them and the issues at stake. These representations are defined by Jodelet (1989) as "*forms of knowledge, socially developed and shared, of a practical nature and contributing to the construction of a reality common to a social group*". In order to achieve this, two surveys were carried out during the first year of the project in the six areas, the first one concerned fish farms with 128 interviews, and the second one all the stakeholders involved in the aquaculture value chain with 168 interviews (table 2). These were face to face interviews using detailed questionnaires combining both closed questions, in particular in the survey on representations, and open questions where textual analysis was used (WordMapper 8.0 from Grimmer soft (p.5)). The first survey aimed to collect data that would enable aquaculture systems to be characterised in the technical, economic and relational senses, to identify the types of farm, the strengths and the constraints, the types of regulation as well as the challenges. Typologies were established and sustainability principles and criteria put into context (Chia et al., 2009; Lazard et al., 2009, 2010). The objective of the second survey was to collate the representations that actors had of sustainable development and the consequences they could foresee for the sector's dynamics (Lazard et al. 2009, 2010). More precisely, this survey made it possible to characterise collective representations, to identify local issues related to aquaculture, to analyse the coherence of the sustainable development model with the current situation of the actors, to analyse the relations and interactions (for example the power systems) within and between the groups and to identify traditional beliefs concerning aquaculture. By integrating international and national norms found in the existing sustainability reference frameworks for aquaculture, this work on representations established a final list of thirteen sustainability principles for aquaculture (fig. 2 and table 3). In addition to the analysis of representations, a systemic analytical framework for aquaculture systems was developed to account for sustainable development. This framework combines all the factors relating to productive systems, to regulatory systems and to the territory and hence enables sustainability to be addressed from two supplementary and interactive viewpoints, which relate respectively to the sustainability factors for aquaculture enterprises and the contribution of these systems to the sustainability of the territory where they are located (fig. 3).

From these principles, a check-list of criteria and indicators was established collectively by the multidisciplinary team of researchers in order to identify the key variables for aquaculture systems. This check-list of principles, criteria and indicators was then validated within the framework of collective working groups comprising the relevant stakeholders in each of the six areas. The purpose was to note, in decreasing order, the principles considered to be the most important and for each selected principle to rank the associated criteria and indicators according to the following categories: "priority", "important", "to be integrated later on", "secondary" or "don't know". By weighting each category with a coefficient (8 for "priority", 4 for "important", 2 for "to be integrated later on", 1 for "secondary"), it was possible to establish scores by country and by types of actor (figure 4). In order to develop indicators, it is necessary to have a good knowledge of the information systems considered to be important in each area so that the new monitoring system for sustainable aquaculture can be positioned relative existing systems. This condition both reduces information collection costs and facilitates understanding and usage of the information system, a part of which will comprise indicators already familiar to actors.

These results were then discussed collectively within the framework of working groups and the results, once adjusted by the group of researchers, were validated for each area. The discussions concerning the prioritisation/selection of the PCIs constituted a collective reflexion process on the issues at stake and the practicalities of sustainable aquaculture. It highlighted, in particular, the principles and criteria that made "most sense" for the actors and the motives behind the rejection of those that were not selected. This procedure corresponds to a negotiated vision of what the actors consider to be sustainable development, of the way in which each one can and should contribute and of the rules used to "judge". It is an essential stage in the construction of a common language and project that is necessary for the implementation of sustainable development. Following the phase of developing sustainability evaluation tools in each country, sustainability diagnoses were undertaken and used to verify that the measurement of the selected indicators was feasible.

Brittany	Cameroon	Indonesia			Mediterranean region				The Philippines	Total
		Tangkit	Cirata	Total	Turkey	Cyprus	France	Total		
Survey No 1: fish farmers										
8	13	29	27	56	9	4	8	21	30	128
Survey No 2: industry actors										
8	2	7	9	16	0	5	4	9	14	49
institutional actors										
18	8	11	7	18	0	7	17	24	15	83
fish farmers (subsample from Surveys No 1)										
4	**5**	**5**	**9**	**14**	**0**	**3**	**4**	**7**	**6**	**36**
Total of actors surveyed in relation to Survey No 2										
30	15	23	25	48	0	15	25	40	35	168
Total of Surveys No 1 + 2										
38	28	52	52	104	9	19	33	61	65	296

Table 2. Survey distribution according to the sites and types of surveys.

Technico-economic dimension	P6- Increase the capacity to cope with uncertainties and crises P7- Strengthen the long term future of exploitations P2- Develop approaches which promote quality
Environmental dimension	P3- Ensure that natural resources and the environmental carrying capacity are respected. P4- Improve the ecological yield of the activity P5- Protect biodiversity and respect animal well-being
Social dimension	P1- Contribute to meet nutritional needs P8- Strengthen sectoral organisation and identity P9- Strengthen companies' social investment
Institutional dimension	P10- Strengthen the role of aquaculture in local development P11- Promote participation and governance P12- Strengthen research and sector-related information P13- Strengthen the role of the State and of public actors in putting sustainable development into place

Table 3. The 13 aquaculture principles and their grouping according to the dimensions of sustainable development.

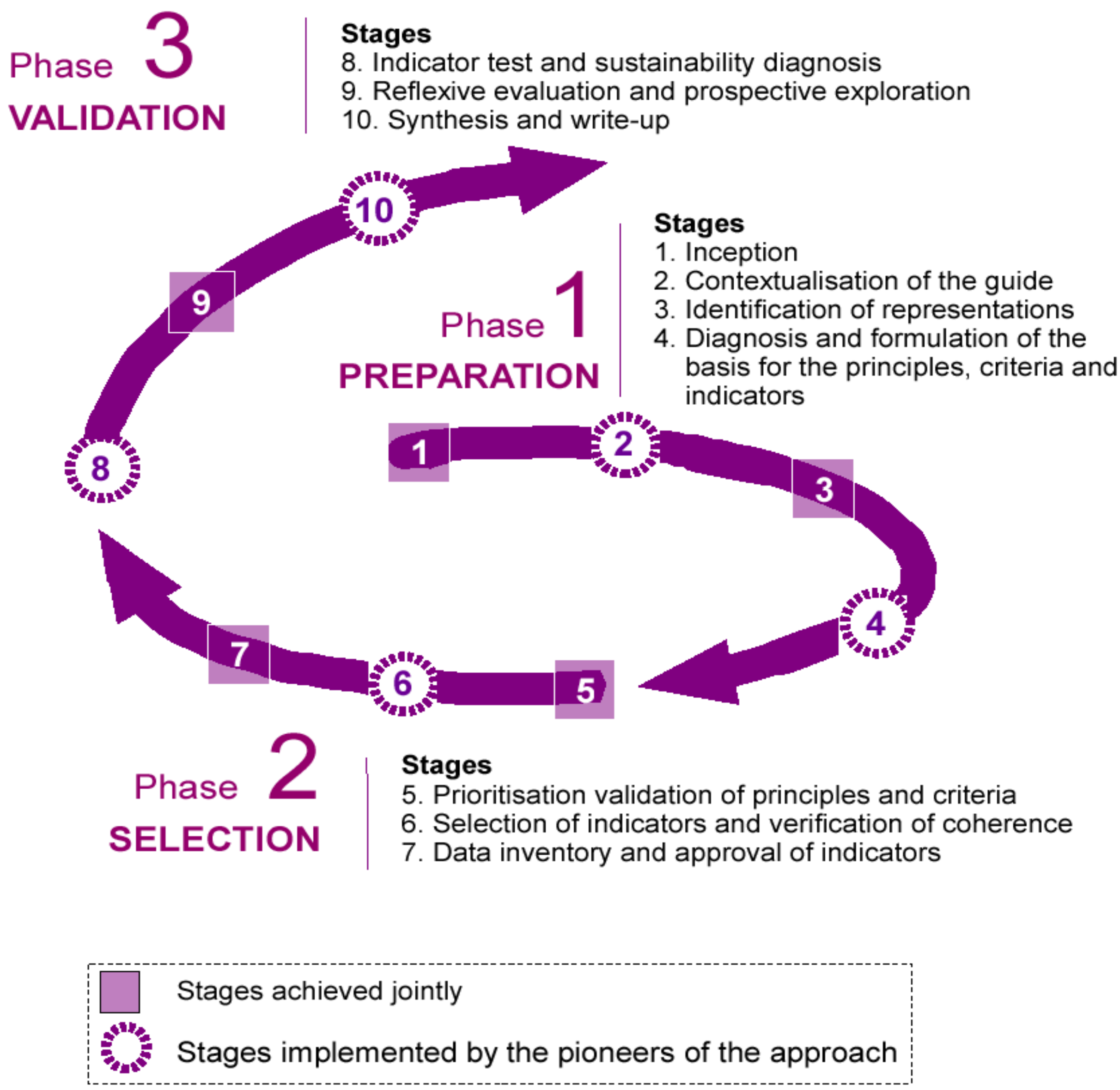


Fig. 1. Implementation process for the co-construction approach.

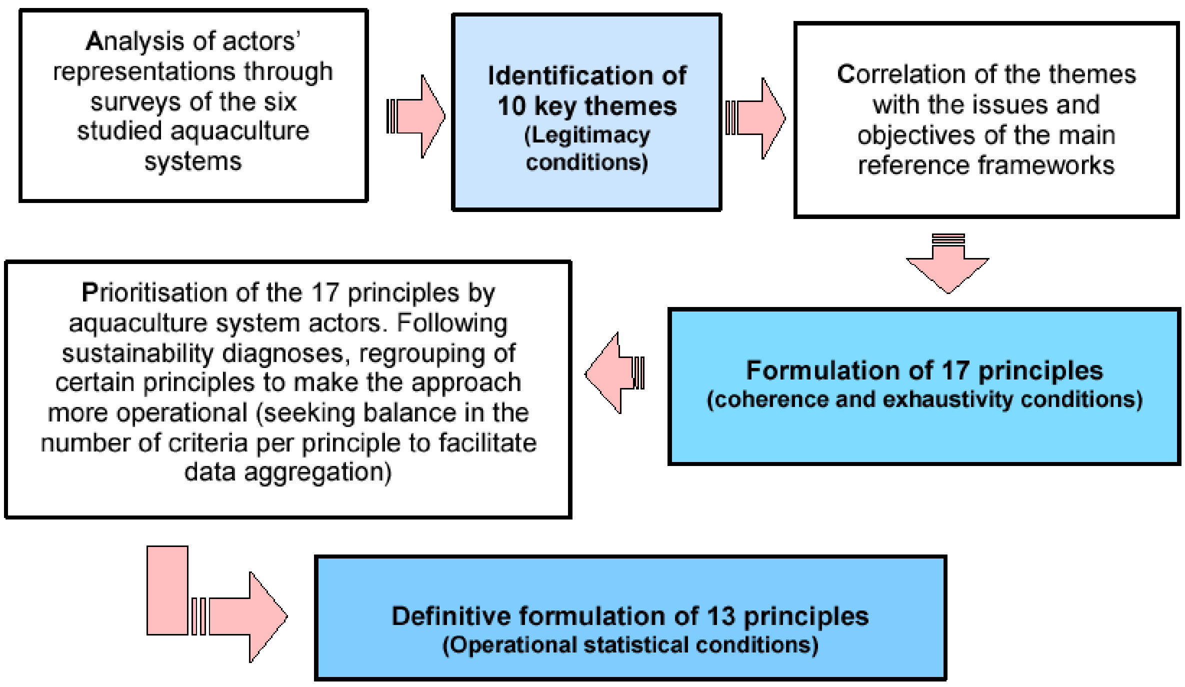


Fig. 2. Traceability of the 13 suggested principles.

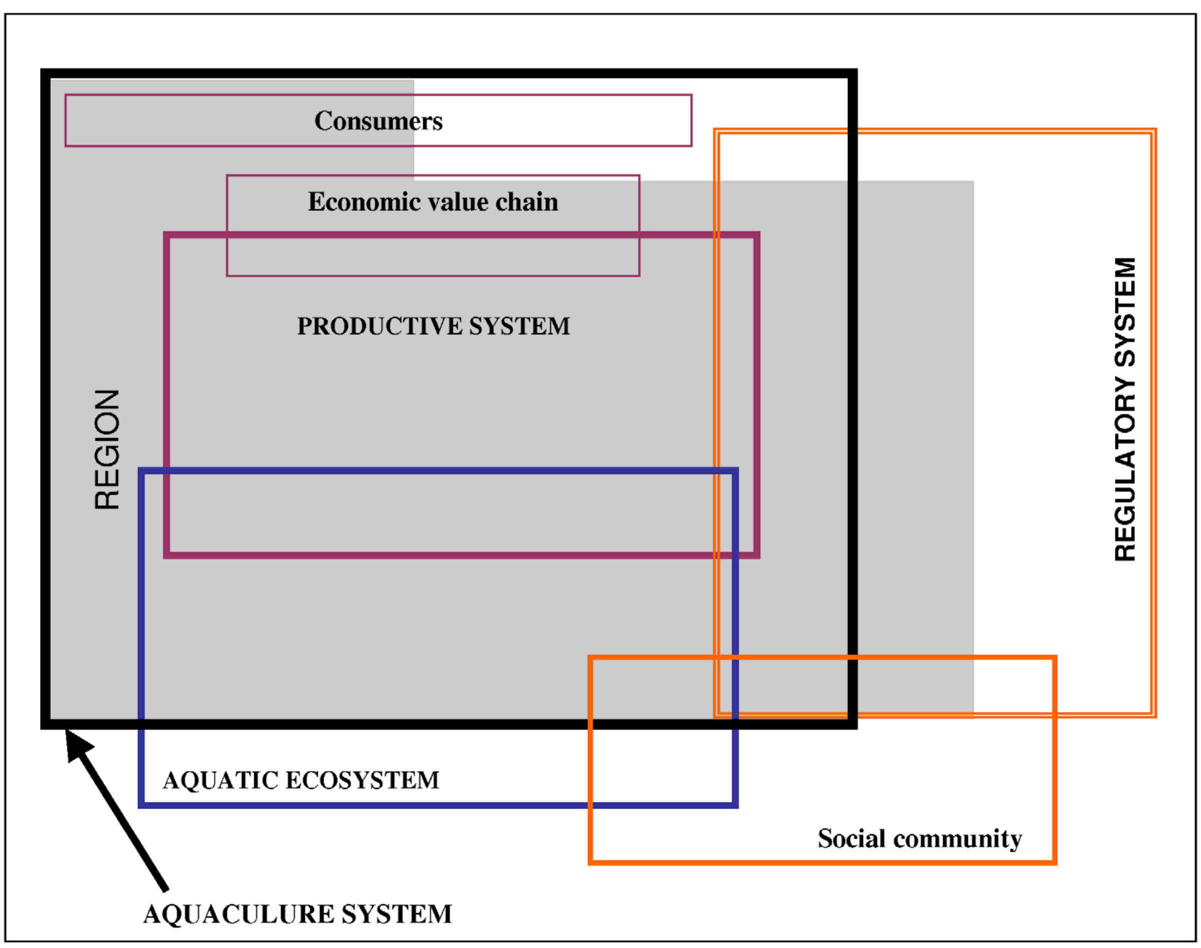
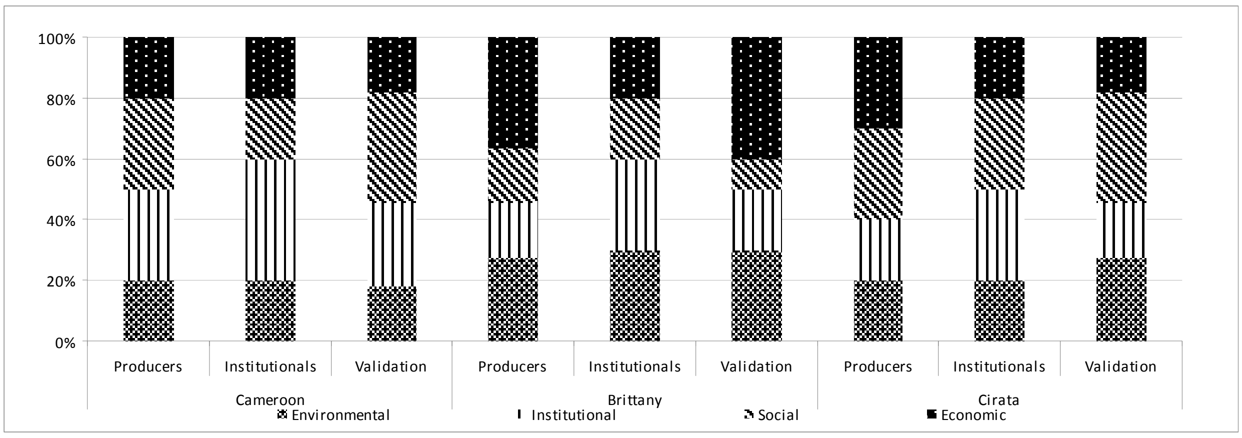


Fig. 3. A systemic approach to aquaculture production systems.



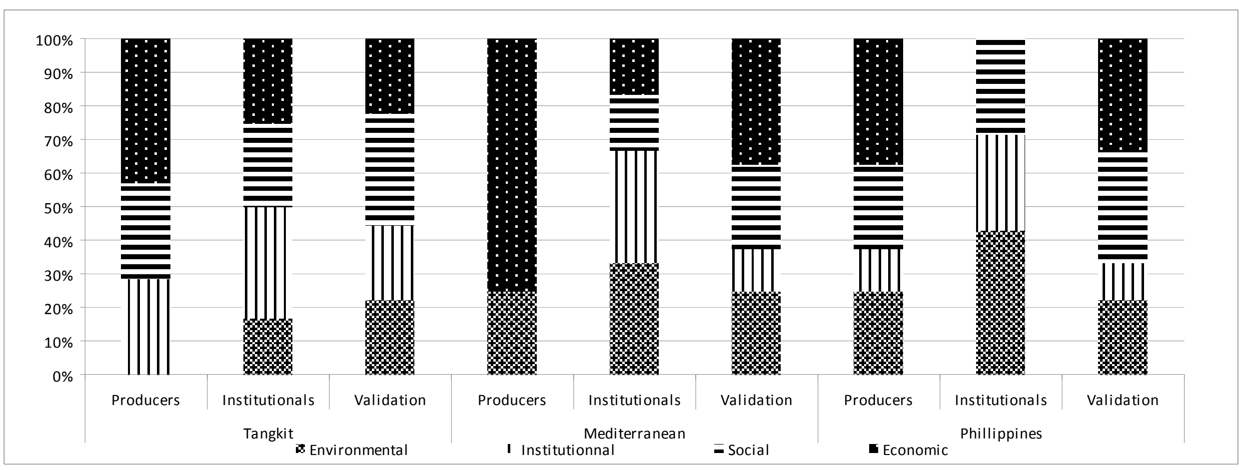


Fig. 4. Distribution of principles during the selection phase (choice of PCI by type of actors) and during the validation phase on the various study areas according to SD dimensions.

5. Applying life cycle assessments to the aquaculture systems under study

The life cycle assessment (LCA) used in the project is a standardised method (ISO, 1997, 2000; Jolliet et al., 2005) used to establish environmental diagnoses of products or services. It is a method for the aggregation of knowledge. It is based on an inventory of all the resources used and of polluting emissions, including the extraction of raw materials, the development of the product, its use and its destruction (thrown away, recycled...). The functional unit selected is **1 tonne of aquaculture product** delivered to the first buyer. The allocation rules between flows are economic (environmental impacts are divided according to the value of the co-products). Calculations were based on the CML method (2001) modified in accordance with Papatryphon et al. (2004). Several categories of potential environmental impact were selected within the project framework as they were considered to be relevant for aquaculture. They are the following: 1) eutrophication (kg PO_4 eq) concerns the impacts on aquatic and terrestrial ecosystems associated with nitrogen and phosphorus enrichment; 2) acidification (kg SO_2 eq) assesses the potential acidification of ground and water due to the emission of acidifying molecules in the air, the ground or in water; 3) climatic change (kg CO_2 eq) assesses the production of greenhouse gases by the system; 4) the use of energy (MJ) concerns all the energy resources used; 5) the use of net primary production (kg C) represents the trophic level of farming from the quantity of carbon used and derived from primary production. For some sites, the following have been added: 6) the water dependency (m^3) defined as the amount of water flowing through the fish farm and required to produce fish; 7) the utilisation of the surface (m^2) which reflects the way the production system takes over the land, including the production of inputs (in particular the crops necessary for the manufacture of aquaculture feed). Work carried out on LCA within the framework of the EVAD project built on the experience of similar approaches already undertaken in aquaculture (Aubin and Van der Werf, 2009; Aubin et al., 2009; Papatryphon et al., 2004).

6. Results

Over and above producing a guide for the co-construction of indicators for the sustainable development of aquaculture (Rey-Valette et al., 2008a, 2008b), the research undertaken made it possible to establish sustainability diagnoses for the different aquaculture systems studied, which, given their diversity, led to very instructive comparisons. The functionality of the approach suggested by the guide was tested when producing these diagnoses.

The diagnoses of the sustainability of aquaculture systems were first established for each area (territorial diagnoses §6.1) then at a global level by developing a synthesis of these diagnoses (into a meta-diagnosis §6.2). These diagnoses were undertaken at the criteria level, which is the most relevant analytical level to qualify the sustainability factors of these systems. The evaluation must be sufficiently detailed by theme to make the diagnosis intelligible. At this criteria level, even if the indicators which constitute these criteria are not all identical, it is possible to compare aquaculture systems. Then aggregating the results at the principles level facilitates comparisons even when selected indicators and criteria are not identical. One of the advantages of this type of approach is to make it possible to compare different aquaculture systems for which sustainability is measured with indicators adapted to the local characteristics and available information. Finally, these approaches based on simple criterion and indicator systems selected in each area were complemented by life cycle assessments for the environmental dimension (§ 6.3).

6.1 Territorial diagnoses of aquaculture system sustainability

Typologies carried out by area showed two differentiation factors common to all areas. These factors were the size of the farm and the nature of the capital or the ownership system associated with other factors, which vary according to the sites and are related to manpower, funding or to marketing methods (Lazard et al., 2009, 2010). These typologies reveal quite a large diversity in production and regulatory systems. Leaving aside the Tangkit site (Indonesia) where aquaculture systems are very homogeneous, three to four differentiated farm types were identified in each area, regardless of whether there was a large number of farms or not. This diversity in sustainability profile can even be found in aquaculture systems where the number of farms is low.

This article will not go into the details of the diagnoses undertaken at each area level. These diagnoses do make it possible to describe the situation of aquaculture systems in detail for each of the criteria in relation to the local context and issues. In order to present a global overview, there are several ways in which to aggregate these criteria. It is possible and important to present diagnoses for the two levels which characterise the approach, i.e. the sustainability of aquaculture farms and the contribution of aquaculture to the sustainability of territories in which each of the systems is located. Criteria can also be broken down according to the four dimensions of sustainability in order to identify in particular, the weaknesses and the strengths by sustainable development pillar. Finally, at a more subtle level, the sustainability profiles can also be considered in terms of farm types. The diversity of strategies goes hand in hand with the contrasting situations concerning sustainability. Hence, the 46 farms in Brittany and the 150 farms in Cameroon may be grouped into 4 sustainability profiles whilst the 18 farms in the Mediterranean (France and Cyprus) are distributed into three profiles. On the other hand, the two areas in Indonesia and the one in the Philippines, which comprise respectively 4,010 and 1,771 production units, are covered by a single sustainability profile.

The global overviews of the sustainability of the various aquaculture systems are presented here (figures 5 and 6) at the principles level in order to facilitate comparison. Working at this level makes it possible to generate general diagnoses by area which highlight the strengths and the weaknesses of the relevant aquaculture system. The aggregation process for principles is mostly based on the average score obtained by the various criteria that make up the principle, in particular when the results correspond to homogeneous or weakly-differentiated sustainability classes. For particular cases, where the principles rest on a restricted number of criteria characterised by very different sustainability scores, we adopted a common arbitration process consisting of choosing some of the selected criteria as the most determinant in the functioning of aquaculture systems. Average values had to be avoided in order to help identify strengths and weaknesses and make the diagnosis as operational as possible to facilitate decision-making and support action plans for sustainable aquaculture.

6.2 Meta diagnosis of the aquaculture systems under study

The comparative analysis of the results obtained for each area establishes several types of finding as regards the sustainability profiles of aquaculture systems and the accompanying policies that need to be implemented. In addition to its qualities in terms of the integration of representations and issues and its capacity to convey comprehensively the various dimensions of sustainability, the PCI method has the advantage of facilitating comparisons between diversified situations. The nesting of sustainability evaluation levels provides several comparative scales for aquaculture systems starting from indicators which are not necessarily the same. Hence comparability constraints and the conditions of adaptation to local specificities can be reconciled. A database was built of the selections made by the actors from different countries. It comprises 13 principles (table 3), 64 criteria and 129 indicators (Rey-Valette et al., 2008a, 2008b). Despite the system diversity, 10 principles and 25 criteria are common to 4 of the 6 areas. The proportion of common indicators is significantly lower with only 30 indicators common to three areas. Although the technical systems under study in Indonesia are very differentiated as regards both farming systems (cages and ponds) and aquaculture operators (farmers and entrepreneurs), there are many criteria common to the two Indonesian areas of Tankgit and Cirata. This observation tends to show the importance of cultural and institutional aspects for sustainability. Inversely, Cameroon, where aquaculture is struggling to develop, is a particular case which stands out from other areas in terms of principle selection and prioritisation. This situation tends to indicate that the degree of maturity of the sector is also a determining factor for sustainability.

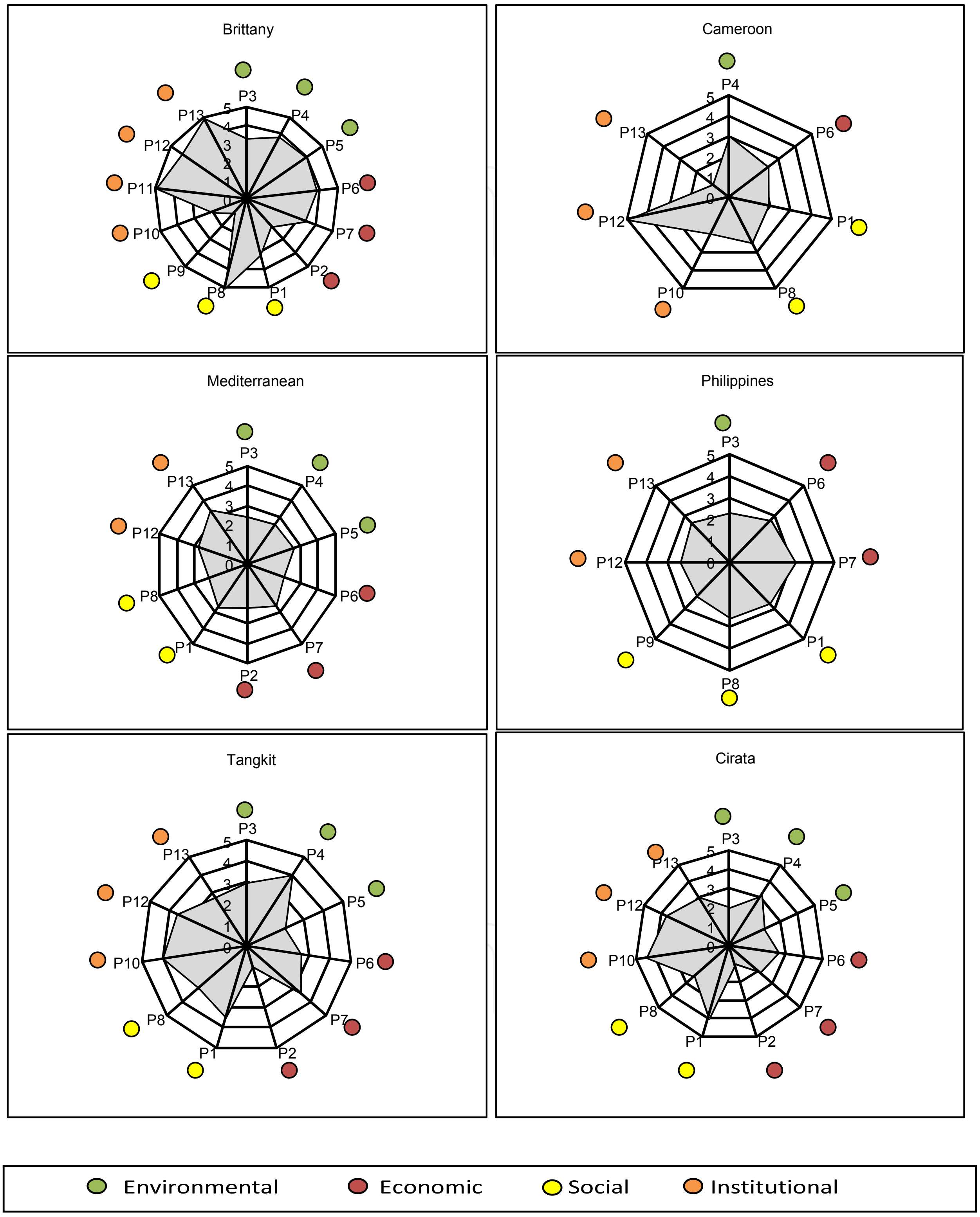


Fig. 5. Evaluation at principle level of the sustainability of aquaculture enterprises by country.

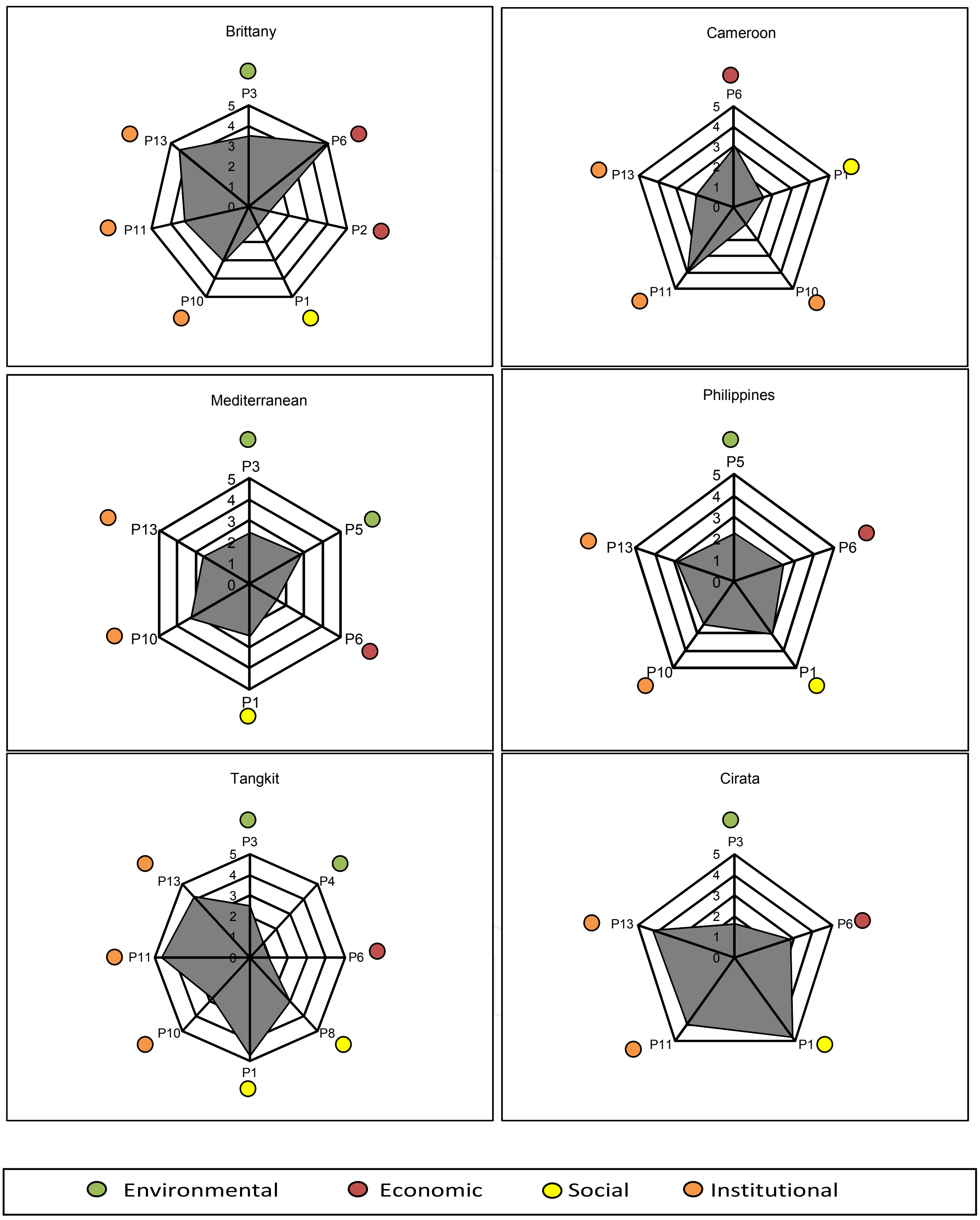


Fig. 6. Evaluation at principle level of the contribution of aquaculture enterprises to territorial sustainability by country.

Given the restricted number of areas studied, the main objective of the comparison process is not to compare the results in an attempt to obtain a universal diagnosis which could not be representative, but rather to study the structure of sustainability profiles and the types of criteria selected according to the areas. Table 3 presents the number of criteria selected by principle, distinguishing between those relating to farm sustainability and those relating to the evaluation of their contribution to territorial sustainability.

The analysis of the relative weights of the 13 principles highlights four principles which are little represented. These are: biodiversity and animal well-being (P5), social conditions within farms (P9), the role of aquaculture as a development factor for the territory (P10) and the capacity to participate in governance arrangements (P11). Overall, although these principles were of little importance, there appears to be a relative equilibrium between the dimensions of sustainable development. The analysis of the results of the selections made by the actors, depending on their status, shows that there are contrasting and specialised visions of sustainability in Tangkit, in the Mediterranean and in the Philippines depending on the type of actors, in particular between the producers who have a very sectoral vision of sustainability and institutional actors with a wider perception (figure 4). These contrasts decreased during the validation phase when actors altered their choice following discussions with other types of actors. Choosing a wide range of stakeholders appears therefore to be an essential condition to ensure an equilibrium between the dimensions, which is itself an essential condition in order to respect the spirit of sustainable development. Furthermore, the analysis of the types of criteria selected according to the area shows that actors tend to select criteria relating to aspects which seem to them to be problematic. This approach is therefore perceived by them as a management and programming tool to bring about progress in their aquaculture systems. This is a different process to labelling approaches or certification schemes which are often linked to marketing strategies and where the emphasis is on the strengths in order to build the image of the sector.

It would seem that the sectoral approach is dominant compared to using the territory as the entry point, as fish farm sustainability involves 46 criteria (60% of which are common to 4 areas) whereas the evaluation of the contributions of farms to territorial sustainability uses only 27 criteria (48% of which are common to 4 areas) (table 4). The share of territorial criteria is 29% for Brittany and 36% for Cameroon, the Mediterranean and the Philippines (table 5). The detailed analysis of the types of criteria selected according to the approach shows that the contribution of aquaculture to territorial sustainability concerns mainly the environmental and institutional dimensions of sustainable development. If we accept that the number of criteria selected is a kind of indicator of actors' awareness of sustainable development, the areas can be divided into three groups of decreasing appreciation: 1) Brittany, 2) the Mediterranean and Indonesia and finally 3) Cameroon and the Philippines.

The comparison of area sustainability profiles at the principle level produces a structural diagnosis of the kinds of strengths and handicaps concerning sustainability. For greater understanding, these results can be shown as "traffic lights", using green in the case of higher level sustainability classes (4 and 5) and red for lower classes (1 and 2), with class 3 corresponding to average scores remaining neutral (figure 7). The analysis of the results makes it possible to establish a typology of the areas in three classes, depending on the relative importance of their strengths and handicaps. Hence, Brittany is relatively well situated in terms of sustainability with, however, differentiated scores according to the various principles. On the contrary, the Mediterranean and the Philippines have more regular profiles which show some homogeneity in the results for all the principles with no outstanding strengths/constraints. Finally, Cameroon and Indonesia have, like Brittany, uneven profiles based on the principles but at a lower level of sustainability.

	Sector	Territorial		Sector	Territorial
Environmental			**Economical**		
P3. Ensure that natural resources and the environmental carrying capacity are respected	**4**	**5**	P6. Increase the capacity to cope with uncertainties and crises	**6**	**5**
P4. Improve the ecological yield of the activity	**4**	**1**	P7. Strengthen the long term future of exploitations	**5**	**0**
P5. Protect biodiversity and respect animal well-being	**1**	**1**	P2. Develop approaches which promote quality	**2**	**1**
Social			**Institutional**		
P1. Contribute to meet nutritional needs	**5**	**3**	P10. Strengthen the role of aquaculture in local development	**2**	**4**
P8. Strengthen sectoral organisation and identity	**6**	**1**	P11. Promote participation and governance	**1**	**3**
P9. Strengthen companies' social investment	**1**	**0**	P12. Strengthen research and sector-related information	**5**	**0**
			P13. Strengthen the role of the State and of public actors in putting sustainable development into place	**4**	**3**

Table 4. Number of criteria selected by the 6 areas according to the principles and dimensions of sustainable development.

	Brittany (France)	Cameroon	Mediterranean	Tangkit (Indonesia)	Cirata (Indonesia)	The Philippines
Sector	42	18	25	33	32	18
Territory	17	10	14	18	14	10
Total	59	28	39	51	46	28
% territory	29%	36%	36%	35%	30%	36%

Table 5. Distribution of the types of sectoral or territorial criteria selected by each area.

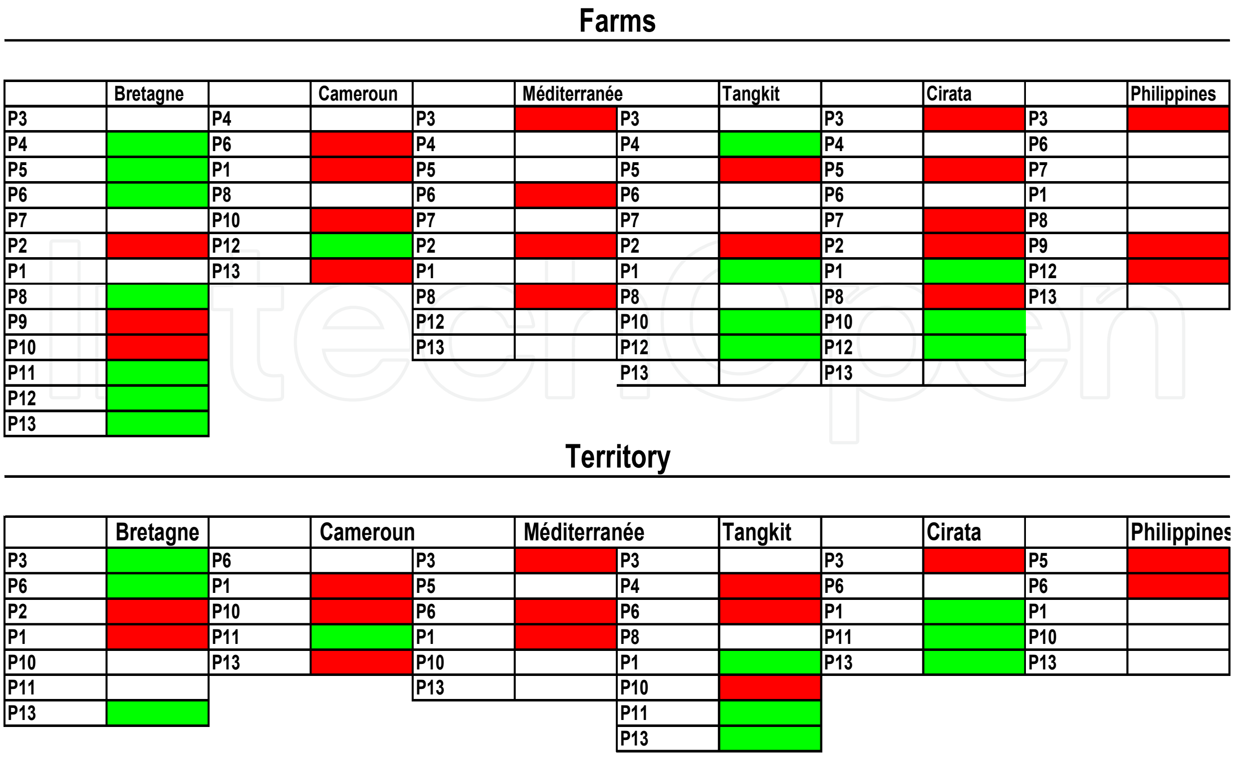


Fig. 7. Stylised presentation in terms of strengths (green) and constraints (red) of the results of the sustainability diagnosis by area in terms of sustainability principles.

This varying homogeneity in the scores is a fundamental result for the definition of sector-specific accompanying policies. Depending on the case, these policies will have to define the measures for regulation, incitation or raising awareness, focusing on a greater or lesser number of factors. This situation means that different types of public policies in terms of integration and progressiveness have to be designed.

6.3 Environmental diagnoses of aquaculture systems based on the LCA method

It will be recalled that this analysis was undertaken by studying 7 factors (eutrophication, acidification, contribution to climate change, and the utilisation of energy, water, surface area and net primary production) in all the areas. The results of the calculation of different impact categories obtained by LCA are presented as a relative evaluation of each of them for the various systems under study (figure 8).

For LCAs undertaken relative to a quantitative unit of production as they have been carried out here, it should be noted that there is no direct relationship between the level of intensification of the farming system and the level of impact. In particular, the Cirata fish farms in Indonesia (cages) and the bass and bream production in the Mediterranean, also in cages, are both very intensive, but show a very low level of impact for the former and a very high level for the latter. This might be explained by the species choice (predominantly plant-eating – omnivorous) and the goal of maximum productivity (by associating species: common carp and tilapia) in the first case and by the choice of carnivorous species (bass – bream) and a poor conversion index in the second case. In Brittany, trout has a profile which is similar to that of bass and bream but with markedly lower impact. This might be explained by the predominant effect of a high protein content feed in the two cases, which affects the level of impact significantly but the food conversion ratio is half in the case of trout. In the case of polyculture in Cameroon, only two impact categories show high levels. These are eutrophication and water dependency. This result shows the poor capacity of the system to utilise the nutrients (nitrogen and phosphorus) brought by the inputs (manuring, wheat bran…) combined with inadequate water management. Polyculture impacts are relatively high in the Philippines. They show the low productivity of the system, in particular due to the significant mortality of shrimp, which are the primary income source in the system. As a result, the quantity of inputs (fish fingerlings, shrimp post-larvae, molluscs for feed, energy…) does not produce sufficient output, and the same is true for land and water. In *Pangasius* fish farms in Tangkit, the predominant impact is the use of net primary production due to excess levels of fish meal (based on local species) incorporated into the feed.

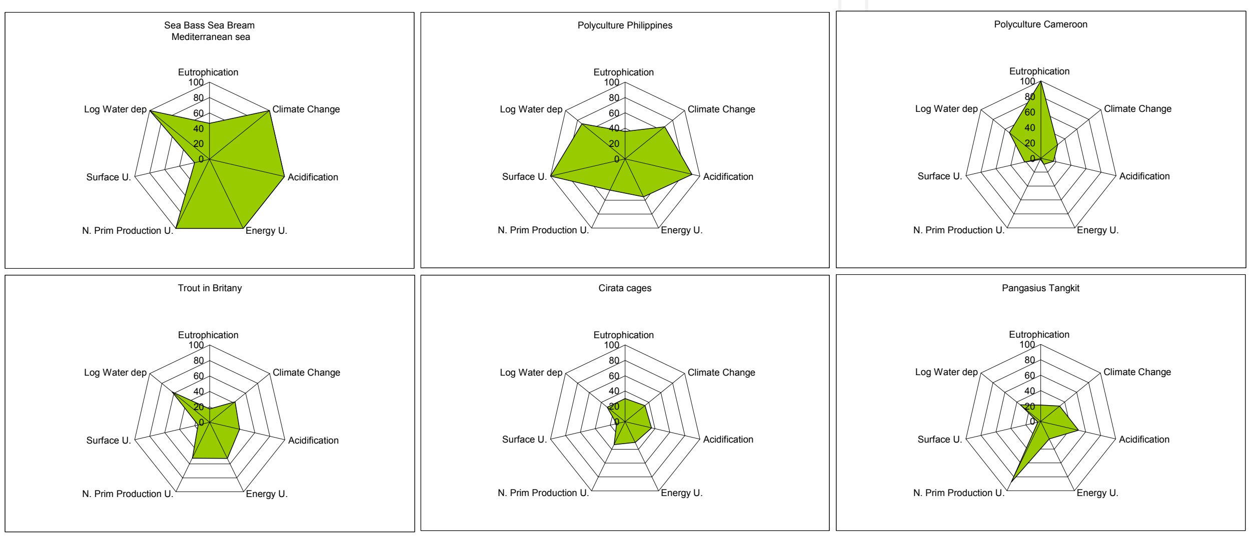


Fig. 8. Environmental profile of the 6 aquaculture systems under study in the EVAD project Radial graphs comparing the relative impact, for seven impact categories, of the 6 fish production systems. Points closer to the centre of the graph have less environmental impact. Values for Water Dependence have been log10-transformed.

7. Discussion and conclusion

First it is important to note the classification of areas with respect to sustainability obtained from the multicriteria evaluation corresponds, in terms of relative priority, to the classification obtained from the results of the life cycle assessment. Hence, in both cases, Brittany (technical model of intensive farming) obtains the best scores whilst more extensive systems, which might have been thought to be closer to natural systems in their environmental dimension and therefore intuitively more "sustainable", score much lower. This result suggests linking results in terms of sustainability with the level of control and of devolved responsibilities, in accordance with one of the definitions of sustainable development proposed by Godard and Hubert (2002) for whom sustainable development consists of "thinking about the consequences of our actions". In general terms, this approach sits within the framework of companies taking sustainable development into account. Corporate social responsibility (CSR) may be defined as the fact that they "*assume the responsibility for the consequences of their actions and take pro-active measures to make their relationships with the rest of society and environment sustainable in the long term*" (Vivekanandan, 2008). According to this author, it leads to the notion of accountability defined as "*the* *responsibility of an actor to justify and account for his actions"* and supposes an adapted multi-level governance. However, in the case of enterprises, these strategies, as noted by Hommel and Godard (2008), do not just aim to integrate ethical issues but also to preserve the image and the capacity of enterprises to operate ("social licence to operate") and may pervert the collective dynamics which sustainable development seeks to initiate. These results, both from the multicriteria evaluation and from the LCA environmental approach, call into question the traditional classification between systems based on natural productivity management and "above ground" controlled systems and therefore most of the recommendations that are typically proposed, which, following in particular Naylor et al. (2000) and on the basis of partial approaches to sustainability, tend to promote more extensive systems.

It should also be noted that the criteria and the principles relating to the institutional dimension of the governance of aquaculture systems and territories were largely selected by stakeholders. This leads into the issue of the countries' political profiles (in particular the levels of decentralisation) and demonstrates the interaction between sectoral sustainable development policies and the political reforms of public action processes. It should be noted that theses aspects are little (or not) taken into account in standards and labels which are usually more focused and based on a sectoral or thematic approach, especially environmental or social. However, it is important to emphasise that these criteria concerning the institutional dimension are generally evaluated on the basis of expert opinion and should therefore be the subject of further research of a methodological nature. Finally, this institutional dimension, which is a governance issue, is increasingly defined as the fourth pillar of sustainable development (Goxe, 2007).

Lessons learnt from work carried out on the areas make it possible to put forward a number of more general conclusions which demonstrate the value of the method.

1. Combining a participatory and procedural approach with the integration of international reference frameworks has proved to be efficient. A fair level of learning and appropriation was achieved during the evaluation exercise yet worldwide the tendency is to establish norms and practices which are intended to apply generally, regardless of the zone or the scale, through "dialogues" and "good practices" originating from top-down work of NGOs and procurement centres (WWF, 2005, 2006, 2007, 2010).
2. The lessons learnt from this project – one proof is the diversity in the choice of indicators – confirms the idea that sustainable development cannot be fractal, i.e. the same content regardless of scale. One dimension which appears to be essential, although usually missing in the field of animal or vegetal productions, is that concerning the contribution of enterprises to the sustainable development of the territory in which they are located. The appropriation of this dimension strengthens local actors when they participate in integrated management arrangements for these territories where they can better defend the contribution of their activity to the territory.
3. This type of participatory approach clarifies that indicators can serve several functions: from simple measurement to the inventory of priorities and including the implementation of local rules. Given the little that most actors from the areas under study knew about the concept of sustainable development, the indicators were clearly useful to give it some sense and bring it within general reach. However, indicators should only be developed once collective representations involving a diversity of stakeholders encompassing all the aspects of the activity have been identified.

4. Finally, between coercion, mimicry and professionalisation (Aggeri et al., 2005) which are different ways to adopt sustainable development, the production of the Co-construction guide (Rey-Valette et al., 2008a, 2008b), broadly disseminated following the project, clearly follows the third route. It emphasises the determinant importance of the choice of route to implement sustainable development for its adoption and the emergence of innovations within aquaculture systems.

It should be noted that this approach to sustainable development is close to the ecosystem approaches (figure 3) suggested by the Millennium Ecosystem Assessment (2005). However, taking this into account would have complicated the definition used for the aquaculture system. It will therefore be useful, as an extension of the work presented here, to test the interest and the social validity of an approach which would question the nature of aquaculture ecosystems and would integrate the notion of services rendered by these ecosystems (Chevassus-au-Louis, 2009; FAO, 2008).

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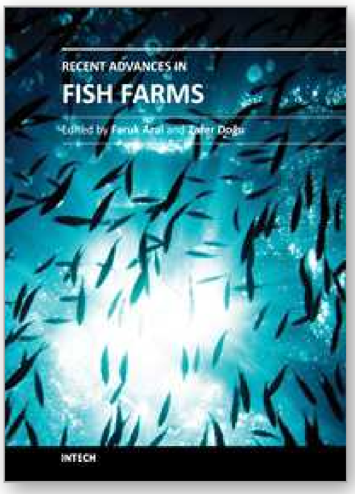

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The world keeps changing. There are always risks associated with change. To make careful risk assessment it is always needed to re-evaluate the information according to new findings in research. Scientific knowledge is essential in determining the strategy for fish farming. This information should be updated and brought into line with the required conditions of the farm. Therefore, books are one of the indispensable tools for following the results in research and sources to draw information from. The chapters in this book include photos and figures based on scientific literature. Each section is labeled with references for readers to understand, figures, tables and text. Another advantage of the book is the "systematic writing" style of each chapter. There are several existing scientific volumes that focus specially on fish farms. The book consists of twelve distinct chapters. A wide variety of scientists, researchers and other will benefit from this book.