ASIRPA

Socio-economic analysis of the diversity of Impacts of Public Agricultural Research

Replacement of marine ingredients by plant products in fish diets

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Context

Within the past 30 years, global consumption of fish and shellfish has increased three-fold, from 50 million tons in 1980 to 131 Mt in 2011 (FAO 2012). Since capture fisheries have remained stable for 30 years around 90 Mt, the increased demand for seafood has been met by aquaculture whose global production has dramatically grown, from less than 4 Mt in 1980 to 67 Mt in 2012 and is expected to be subjected to a 33% further increase until 2021 (FAO 2012). Intensive fish farming as is practiced in the developed countries relies exclusively on the use of complete feeds formulated to meet the nutritional requirements of the target species. In the 80's, feeds for fish were developed based on available knowledge on the nutrient requirements of rainbow trout and had high protein levels. Indeed, compared to terrestrial farmed animals, fish are recognized to have higher dietary protein requirements (especially for cold water species such as salmonids and marine species produced in Europe), lower energy requirements, specific needs for long-chain ω3 polyunsaturated fatty acids (PUFA) and to exhibit poor utilization of dietary carbohydrates. Such high requirements for dietary proteins are also associated with significant nitrogen waste resulting from excess amino acid catabolism. The feed efficiency (measured as unit gain in mass / dry feed intake) as well as the digestibility of such feeds was rather low. Excess dietary protein and low digestibility mainly of indigestible carbohydrates were major concerns due to the potential impacts on the environment resulting from fecal and non-fecal losses. As with many farmed animals, cost of feed represents a major portion of the total production costs (more than 60%), so that protein economy is one major issue both from the scientific point of view and for the overall economics of the sector.

Another major issue is the reliance of aquaculture on feeds relying heavily on fish meal (FM) and fish oil (FO) (FM and FO are commercial products made from dedicated industrial fishery captures) as sources respectively of dietary essential amino acids and essential fatty acids required by fish. This led to studies dedicated towards optimization of dietary protein quality using alternative protein sources. While aquaculture has been on a continuous increase over the past three decades, with an annual growth rate of about 6%, the availability of FM and FO has at best been stable over the same period reflecting the overall stability of global pelagic fish landings that have been subjected to limiting allowable catches in order to preserve environmental marine resources. Thus, fish farming relying on FM and FO as feed ingredients was recognized as not a sustainable practice over the long run. The increase in demand in FM and FO for growing aquaculture sector combined with regulatory measures on fishing (total allowable catch limits, quotas), climatic factors (El Niño effects) or societal issues (forage fish as food for man) have led to disparities in supply and demand of FM and FO and a consequent increase in **price and market volatility** for such feedstuffs. Aquaculture is by far the largest consumer of fish meal and fish oil. Aquaculture uses more than 73% of fishmeal i.e. far more than world demand for pig (20%) and poultry (5%) feeding. Aquaculture also accounts for 81% of the use of fish oil, the amount of FO consumed in food supplements and medicinal products for human use reaching only 13%. The most common alternative ingredient to fishmeal in commercial fish diets is soya bean meal, the cost of which is much lower (500US$/ton in 2014 as compared to 2000US$ for fish meal). Although the price of soya bean meal was multiplied by 3.3 between 1994 and 2014 (from approximatively 180 US$ in 1994 to 500US$ now, Fig. 1), this increase remained lower than that of fish meal (multiplied by 4.8 during the same period; from 600US$/ton to more than 2000US$/ton in late 2014, Fig. 1). Price of fish oil has also highly evolved during the last decades reaching its highest value in 2008 (1230€/ton) however fish oil prices remained in the same ranges compared to plant oil prices.

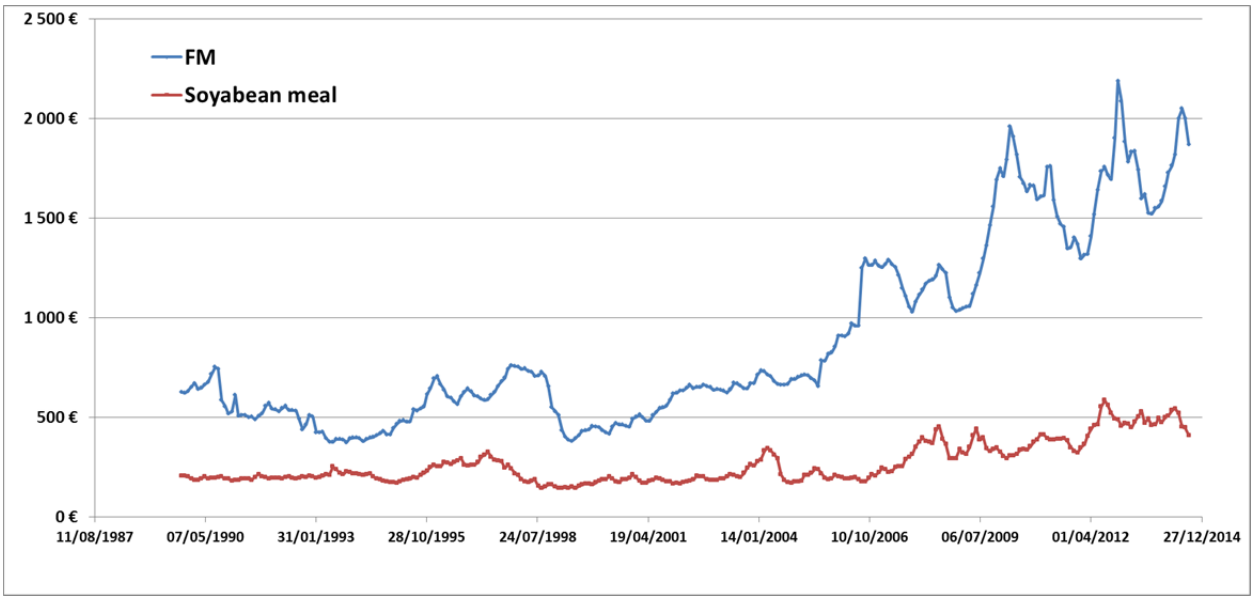


Figure 1: Evolution of fishmeal and soya bean meal price from 1994 to 2014 (US$/ton) (source indexmundi.com)

In this context, the use of alternative raw materials in fish feed formulation has become even more essential to meet the increasing needs of a sector in full expansion. The main implemented solution was to increase the substitution of FM and FO by plant products, particularly in Europe where the use of terrestrial animal by-products was banned as an initial French voluntary policy decision in 1998 confirmed in 2000 by legislation at the European level following the mad cow disease crisis. Plant sources offer several advantages including diversity and availability but also provide constraints linked to lower protein content, different amino acid profile, and substantial carbohydrate supply for plant protein sources and different fatty acid profiles in vegetable oils. However, the use of such alternative protein and fat sources also leads to other considerations such as competition with other animal production sectors, possible reduction in performance of fish reared with such feeds, the physiological or metabolic consequences and possible effects on the nutritional quality of fish as human food.

Inputs and productive configuration

1. Longstanding data collection on fish metabolism and voluntary intake

Research work performed by INRA in the Fish Nutrition Laboratory at Saint Pée sur Nivelle, in the 80s demonstrated that a significant proportion of dietary amino acids was used by fish for energy production (Cho and Kaushik 1985; 1990). In order to limit the negative impact of aquaculture on the environment and to reduce the dependence of aquaculture on fishmeal derived from capture based fisheries, two strategies were simultaneously explored: i) increasing the digestible energy content of the diet by incorporation of fats and digestible carbohydrates and ii) putting special efforts on the substitution of fishmeal protein by alternative sources of proteins. Studies undertaken by the INRA Fish Nutrition Laboratory used rainbow trout as a model species, which happens to be the number one finfish species produced in France. However, in the framework of collaborations, comparative studies were performed on other fish species (salmon, sea bass, sea bream, carp…) in order to verify and extend knowledge gained with trout to other fish species.

Research undertaken to investigate the impact of fish meal (FM) and fish oil (FO) replacement on fish farmed in Europe was undertaken and financed by several EU funded projects: PEPPA (2000-2003), GUTINTEGRITY (2001-2010), PUFAFEED (2000-2003), FPPARS (2000-2011) and RAFOA (2001-2006) and more recently AQUAMAX (2006-2010), by European consortia composed of several laboratories working on different fish species and different aspects of fish nutrition. The contribution of

the Fish Nutrition research unit of INRA (known as “Nutrition, Métabolisme, Aquaculture” NuMeA INRA research unit) was mainly related to rainbow trout nutrition, metabolism and growth. Observatories and technological platforms from INRA and its partners enabled the collection of longstanding data about nutritional requirements and metabolism. Experiments performed by INRA in different projects (Aquamax, Peppa, Rafoa…) were conducted in Donzacq and Lees Athas, the INRA fish farm facilities of the fish nutrition group where rearing and feeding conditions are highly controlled and allow the record of a larger panel of reliable parameters compared to an industrial fish farm. These research efforts were undertaken also in cooperation with feed producers that were in charge of the development of feed manufacturing and feed production and with fish farmers whose farming facilities were used to test new feeds in industrial production conditions.

As examples, studies performed on fish energy requirement and carbohydrates digestibility were initiated by the Fish Nutrition Laboratory in collaboration with the French Company of Animal Nutrition COFNA. The feed producers NUTRECO and Biomar contributed also significantly to the research implemented by INRA through the development of the extruded fish feed pellet within the framework of the European projects.

At the national level, work was also undertaken in cooperation with other INRA research units such as SCRIBE i.e. the current "Fish Physiology and Genomics lab" (LPGP Rennes) and UMR as well as experimental units such as PEIMA. SAS, in collaboration with the Fish Nutrition Laboratory (NuMeA) also created, coordinated and maintained in the long term a database on the environmental impacts of various fish species and of different fish farming systems worldwide. This database was the key enabling facility to allow Life Cycle Analysis (LCA) on different fish species and production systems.

2. Feasibility of replacement of protein sources: from fish meal to plant-based protein

Initial research initiated by INRA on fish meal replacement by plant protein was undertaken during the PhD thesis of Christine Burel in collaboration with professional partners from plant production (CETIOM, UNIP). During this collaboration, studies were oriented toward the assessment of the digestibility of plant protein sources and the potential disturbances due to anti-nutritional factors. Thereafter, the PEPPA European project (Perspectives of Plant Protein usage in Aquaculture) coordinated by the INRA Fish nutrition laboratory established that fish meal in fish feeds containing fish oil could be largely replaced by plant protein sources. Within this project, the firm GIRA was in charge of conducting survey to assess the social acceptability of salmon produced from aquaculture. They concluded that fish has a very positive image (less cholesterol, more calcium, more vitamins, omega 3 fatty acids, no blood, low fat…) but acceptability differed between countries according to cultural and eating habits. Regarding utilization of plant ingredients in fish feed, UK consumers would easily eat vegetarian fish, French consumers would consider it as a transgression against nature, and Italians would be shocked if a healthy carnivore became a “degenerate vegetarian”.

3. Feasibility of replacement of oil sources: from fish oil to plant-based oil

The RAFOA European project in which INRA (Fish Nutrition Laboratory) was partner was undertaken in close collaboration with the feed producer Trouw-Nutreco who was in charge of the production of all experimental feeds developed during the project. This project established that much of the fish oil currently used in the production of salmon, rainbow trout, sea bream and sea bass can be replaced with a blend of vegetable oils without compromising the growth performance of any of the species and that the changes in the fatty acid compositions of the fillets resulting from the vegetable oil blend can be largely reversed in all species with a "finishing diet" containing fish oil.

4. Combining the replacement of fish meal and fish oil

The potentiality of simultaneous substitution of fish meal and fish oil by plant proteins and vegetable oils was further addressed in the FP6 AQUAMAX European integrated project, where INRA was in charge of the Aquaculture component. The primary application of AQUAMAX was the development of feeds with low FIFO ratio (Fish In/Fish Out) thus enhancing the sustainability of the industry while ensuring

the nutritional value (fatty acid profiles) and food safety (minimal levels of contaminants) of fish thus produced. Their health benefits and acceptability by the consumer were demonstrated by our partners in the medical research domain. Two French companies were involved in this project, Viviers de France who conducted feeding trials using plant-based diets in industrial conditions of trout production and Alpha Mos who performed sensory analysis of products. Another outcome of the AQUAMAX project was the identification of bottlenecks that impede the total replacement of FM and FO concomitantly. Strategies for overcoming such brakes are the objectives of the ongoing European Project ARRAINA, coordinated by INRA-NuMeA.

Research outputs

The outputs of research were knowledge that has been further used as basis by feed producers to change the formulation of fish feeds.

Basic principles for fish feed were published in several books, exposing and validating replacement of marine ingredients by plant raw materials.

In 2000, a book entitled "Nutrition des Poissons et des Crustacés" was produced in majority by the members of the research units of INRA to summarize the main principles of fish nutrition based on data about nutritional requirement and metabolism. This book was later translated into English and Spanish.

The interest and limits of **alternative protein sources** in aquaculture diets were addressed in the book published in 2008 by Lim C, Webster CD, Lee CS, following an international symposium on this topic in which members of the INRA fish nutrition group participated.

The interest and limits of f**ish oil replacement by vegetable oils** were addressed twice in 2009 in the "Cahiers de l'Agriculture" and in a book dedicated to "Fish oil replacement in finfish nutrition" published by Turchini et al. with the collaboration of members of the INRA "Fish Nutrition Laboratory".

A specific chapter about replacement of fish meal and fish oil was included in the compendium of 2011 on "Nutrient requirements of fish and shrimp", produced by the National academy of Sciences of the US, by an experts group to which Françoise Médale (Research director INRA) participated.

Finally, an assessment of the situation regarding the joint substitution of fish meal and fish oil was performed in 2013 in a review published in "INRA Productions Animales" (Médale et al., 2013).

Results related to voluntary feed intake

The European project GUTINTEGRITY where INRA was a major partner showed differences in feed intake due to oil sources and identified that intestinal absorptive capacities were modified by ingredient substitution. Results of this project presented in several conferences have been used as basic knowledge by feed producers for the choice of vegetable oil replacing fish oil.

Food products assessment methods and recommendations for formulation

The issue of fish meal and fish oil substitution has been addressed at several levels including fish feed ingredients evaluation and determination of the consequences on feed intake. Research from INRA contributed to identify critical points for food formulation and ingredient selection. A list of nutritional and digestibility factors was established and a specific effort was made to introduce data relative to fish species in the book edited by INRA entitled "Tables de composition et de la valeur nutritive des matières premières destinées aux animaux d'élevage" (2004). This book was translated into English, Spanish and even Chinese. Another book was produced in 2001, in the frame of the COST Action 827 to present the factors affecting voluntary feed intake in fish at a crucial moment for the development of new management techniques in fish feeding.

The two main recommendations from INRA were to formulate food products based on nutrients instead of ingredients, and to use a finishing diet containing high level of marine FO for a short period just

before harvest. This finishing diet partially restored omega 3 fatty acid levels in the flesh. It was also recommended to limit the utilization of linseed oil that negatively affects fish appetite and flesh taste.

Database enabling Life Cycle Analysis

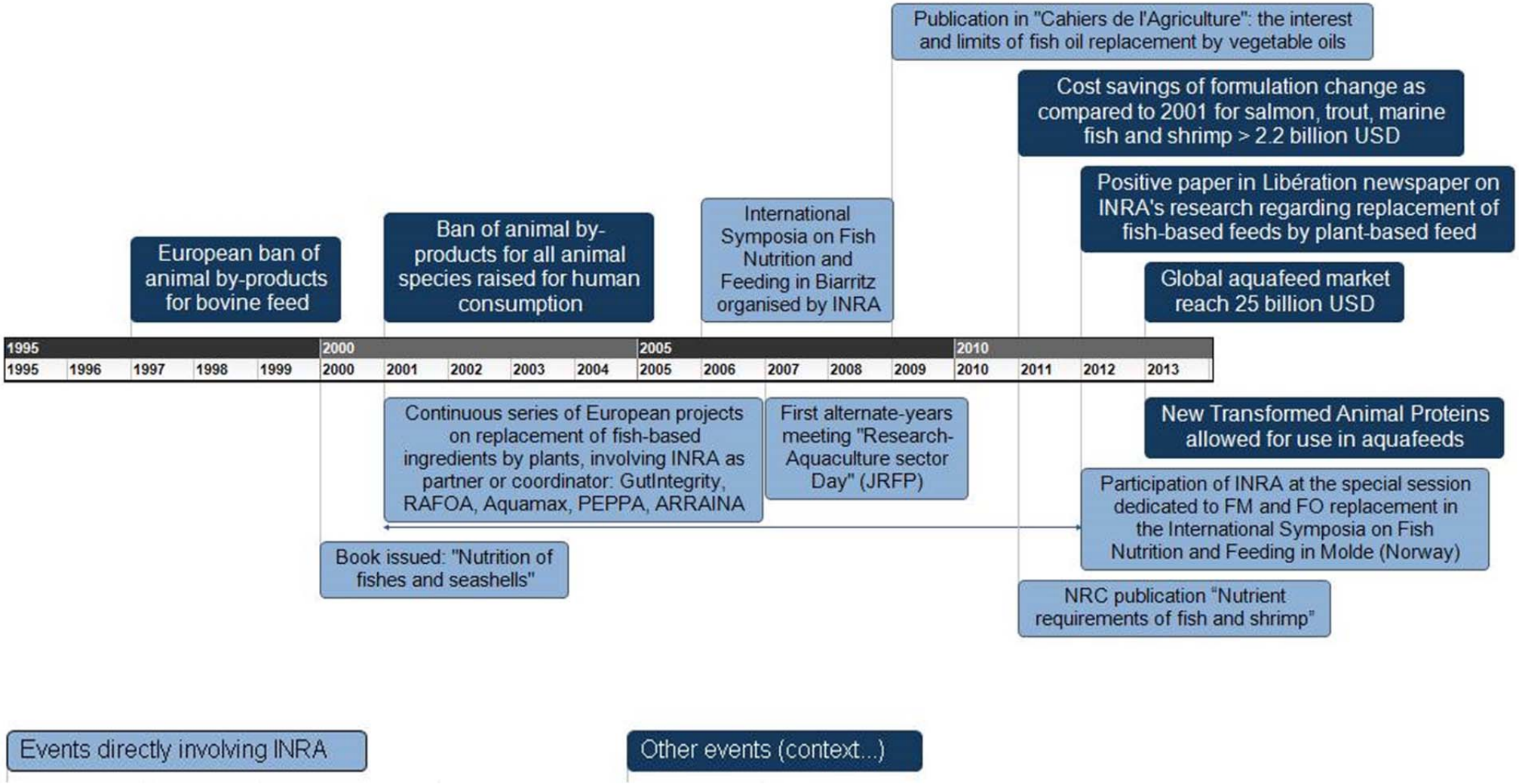
A database was created by INRA (SAS Unit Rennes) by collecting environmental indicators from different farming systems around the world and data about production of food ingredients. The calculation of LCA of a diversity of situations demonstrated that there is no ideal food ingredient minimizing environmental impact whatever the conditions. Therefore the conclusion was that LCA had to be performed on feed rather than on each ingredient and that the whole production system had to be considered.

Apart from the outputs cited above, the knowledge generated has led to a number of excellent scientific publications, among which:

- Kaushik S.J., Cravedi JP, Lalles JP, Sumpter J, Fauconneau B, Laroche M., 1995. Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic effects, cholesterolemia and flesh quality in rainbow trout. Aquaculture 133: 257-74.

- Panserat S., Kolditz C., Richard N., Plagnes-Juan E., Piumi F., Esquerré D., Médale F., Corraze G., Kaushik S., 2008. Hepatic gene expression profiles in juvenile rainbow trout (Oncorhynchus mykiss) fed fish meal or fish oil free diets. Br. J. Nutr., 100, 953-967.

Chronology


Publication in "Cahiers de l'Agriculture": the interest and limits of fish oil replacement by vegetable oils
Cost savings of formulation change as compared to 2001 for salmon, trout, marine fish and shrimp > 2.2 billion USD
Positive paper in Libération newspaper on INRA's research regarding replacement of fish-based feeds by plant-based feed
Global aquafeed market reach 25 billion USD
European ban of animal by-products for bovine feed
Ban of animal by-products for all animal species raised for human consumption
International Symposia on Fish Nutrition and Feeding in Biarritz organised by INRA
1995
2000
2005
2010
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Continuous series of European projects on replacement of fish-based ingredients by plants, involving INRA as partner or coordinator: GutIntegrity, RAFOA, Aquamax, PEPPA, ARRAINA
First alternate-years meeting "Research-Aquaculture sector Day" (JRFP)
New Transformed Animal Proteins allowed for use in aquafeeds
Participation of INRA at the special session dedicated to FM and FO replacement in the International Symposia on Fish Nutrition and Feeding in Molde (Norway)
Book issued: "Nutrition of fishes and seashells"
NRC publication "Nutrient requirements of fish and shrimp"
Events directly involving INRA
Other events (context...)

Knowledge flow and intermediaries

During the last 20 years, several means were used to widely disseminate the results of the research related to fish meal and fish oil substitution in fish feeds. INRA played a major role in providing scientific information and recommendations that stakeholders transformed into new feed formula. The knowledge transfer is mostly based on longstanding interpersonal relations, project collaborations and specific conferences.

- **INRA's scientific advice regarding formulation:**

INRA's research highlighted that there is no ideal formulation since the products result mainly from the selection of proper ingredients by food producers. INRA issued two recommendations in terms of nutrients requirements and indicated limits of incorporation for different raw materials.

In order to coordinate and disseminate the outputs of the European projects, a **concerted action** was initiated. The principal purpose of the action called "FORM" was the dissemination of major findings to all stakeholders not previously involved in the projects. The first objective of FORM was to optimise scientific networking, management, co-ordination, monitoring and exchange of information on a volunteer basis, by utilising and expanding existing activities from the on-going EU-funded projects. FORM contributed strongly to the diffusion of knowledge to all international fish feed producers. Following the FORM meetings, they changed their practices towards an increasing incorporation of plant ingredients in fish feed formulae. The outcomes of INRA research on fish meal and fish oil replacement by plant ingredients were presented to a large community of scientists and stakeholders at a series of International Symposia on Fish Nutrition and Feeding, including one organized by the INRA fish nutrition lab in Biarritz in 2006 (480 delegates, a third of professionals) and in Brazil in 2008, in China in 2010 and in Norway in 2012 that many INRA delegates attended to give communications in a special session dedicated to fish meal and fish oil replacement.

At the national level**, regular events** were organized to allow the dissemination of research outcomes in the area of nutrition to all stakeholders (feed ingredient providers, fish feed producers, fish farmers). These events had a clear focus on providing the most up to date research directly to the aquaculture industry sector. As an example, the INRA Fish nutrition lab contributed to the creation of the symposium "Les Journées Recherche Filière Piscicole" (JRFP) in 2007 and participated in the organization of the subsequent editions in 2009, 2012 and 2014. More recently, the INRA Fish nutrition lab played a major role in the organization of "les Journées Nutrition des Poissons" at Saint Pée sur Nivelle in spring 2013. This event held under the supervision of the Scientific Group " GIS Fish Farming Tomorrow" and professional associations (ITAVI, CIPA and FEAP) brought together over 130 participants, two thirds were professionals from aquaculture industry. It is worth mentioning the presence of the three main international fish feed producers, who contributed to this event by giving a common vision despite the fact that they are competitors.

The involvement of extension services such as ITAVI (technical institute for poultry and fish farming), CIPA (Interprofessional Committee of Aquaculture Products) and FEAP (Federation of European Aquaculture Producers), dedicated to transferring research knowledge to professionals, improves knowledge circulation in their respective networks. These technical centers also promoted actively Life Cycle analysis. CIPA launched a survey in order to assess the different feedstuffs potential available as feed ingredients on the basis of many criteria including life cycle analysis. ITAVI controls the enforcement of various regulations, including the collection of a tax related to the level of outflow of fish producers. ITAVI thus indirectly encourages farmers to reduce their environmental footprint.

- **Advice regarding aquaculture practices. A recommendation was addressed to fish farmers by European scientists** (including those from INRA) about the efficiency of a fish oil finishing diet in order to restore the ω3 fatty acid composition of the flesh after long term feeding fish with plant based diets. The implementation of this practice requires the collaboration of farmers because this practice results in an increased workload and a reduced flexibility in fish stocks management. Farmers are thus

key intermediaries for the adoption of this "finishing diet" strategy which is nowadays the only solution for restoring high levels of long chain ω3 fatty acids in the flesh of fish fed plant-based diets on the long term.

- **The role of supermarkets (as influenced by the societal demand),** particularly buyers from supermarkets, was also crucial in the evolution of fish feed formulations. Since supermarkets dictate products' specifications to their providers (fish farmers), they represent potential barriers but also leverages to the utilization of plant ingredients in fish diets. Carrefour supermarket was a pioneer who accepted, after many exchanges with INRA, to integrate plant-based diets in their recommendations to fish producers. This decision was then followed by other supermarkets including Intermarché.

- **Non-governmental organizations (NGOs) also took part in the diffusion of outputs.** INRA was in the forefront with the International Union for the Conservation of Nature (IUCN), for the development of indicators for sustainability and good practices for French Salmonid aquaculture. These data are available to inform supermarkets decisions and consumers habits and contributes to disseminate good practices.

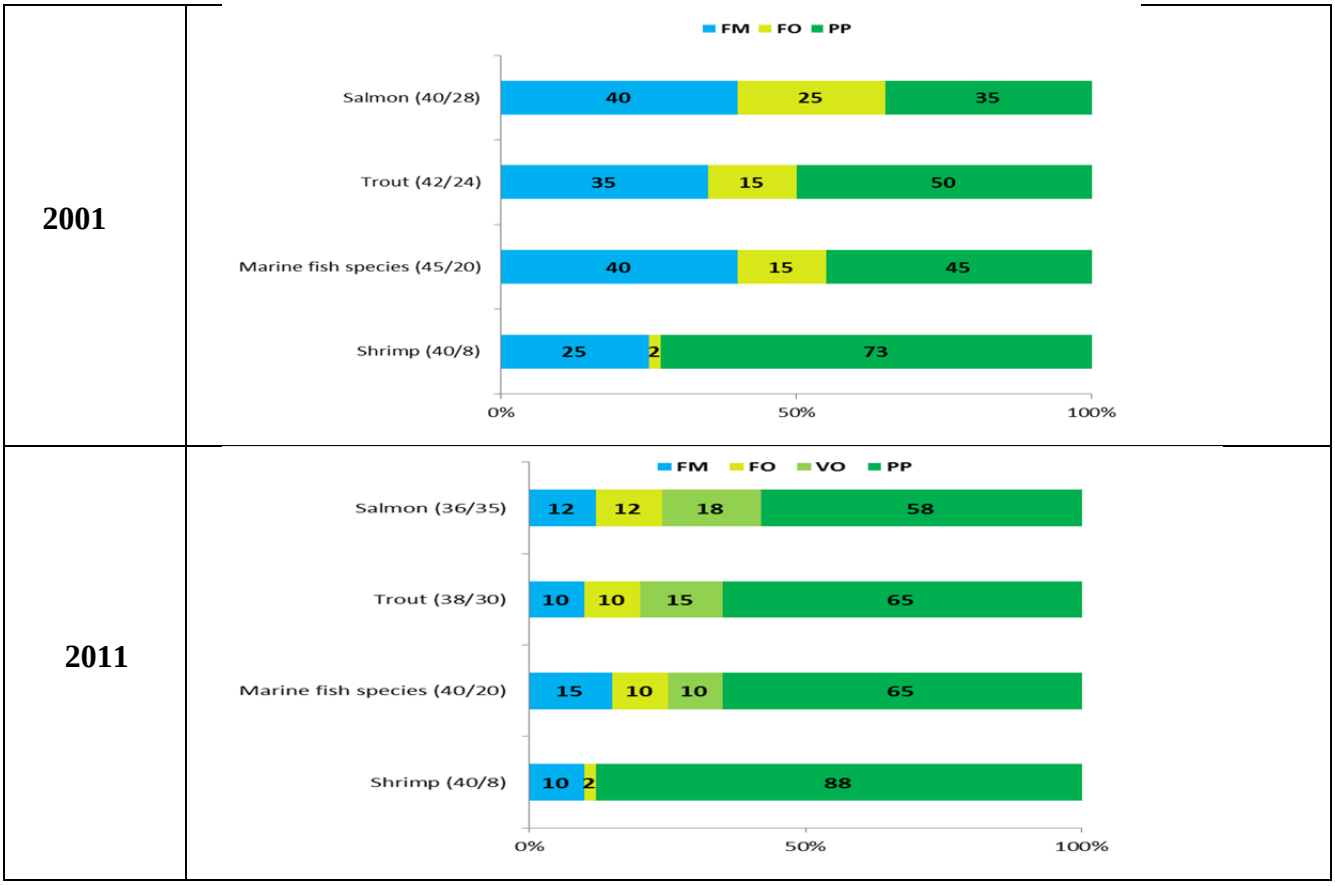


Figure 2: Evolution of fish feed formulation between 2001 and 2011. FM: Fish Meal, FO: Fish Oil, VO: Vegetable Oil, PP: Plant Proteins (Into brackets protein/fat contents as % of dry matter). Adapted from Le Boucher et al., INRA Prod. Anim. 2013, 26 (4), 303-316.

The research has led to significant **reductions in the inclusion of fish meal and fish oil in feeds used for European fish farming**, which have been replaced mainly by plant-derived alternatives, complying fully with European legislation ("Framework Directive on water" in 2000, Directive 2006/88/CE October 2006 relative to sanitary conditions of fish and fish products, prohibition of terrestrial animal-based meals in animals intended to human consumption in 2001, European re-introduction of poultry and pig protein utilization in fish feeds in 2013…). Whereas fish meal contributed to 35 to 40% of feed for trout and salmon respectively in 2001, its proportion was reduced to 10 to 12% ten years later (see figure 2 below). A significant fish oil reduction was also observed during the same period.

Environmental impact:

Using Life Cycle Analysis led to the implementation of multi-criteria approaches to take into account the different components of sustainability: economic, social and environmental. This standardized method is now becoming adopted in aquaculture industry to assess the environmental impact of feeding practices and support strategic choices. With the introduction of plant-based ingredients, the number of ingredients available for food formulation has increased (from 10 to around 50 ingredients). This gives food producers more flexibility to improve the results of the LCA of their products while optimizing their costs and nutritional quality. LCA of sea bream production with standard or plant based diet show very similar environmental performances for eutrophication, climate change, energy and water use, and acidification, showing that the environmental impact of fishing and fish oil extraction can be completely replaced by impacts associated with crop and vegetable oil production. Although the substitution showed

a beneficial effect on the use of net primary production, as reflected by the reduction of the pressure on marine resources, a significant increase in the use of land surface dedicated to the production of the vegetable ingredient was observed, which could ultimately put aquaculture at the same level livestock in the competition for land use.

Social impact

Replacement of marine ingredients by plant products in fish feeds responds to societal concerns related to the growing global food demand, and the sanitary risks of using animal-based meals following the BSE crisis. As a result of these concerns, changes were made in the **specifications of supermarkets** (Carrefour) at the end of nineties and in specific labels ("Label rouge" for salmon, trout, sea bass and turbot) in the noughties. Incentives to change the food diet of farm fish toward a more sustainability increases the acceptability of fish farming in general. The publication of the article entitled "Where the trout grazes" ("Là où broute la truite", Sylvestre Huet, 29 November 2012) in the newspaper "Libération" describing vegetarian fishes as a promising solution to sustain growing global fish demand while decreasing over-exploitation of oceans' resources, the article published in "Le Monde" (August 2012) about the future of world aquaculture with an interview of Françoise Médale about changes in fish feed composition, as well as the interview of Richard LeBoucher (PhD student INRA fish groups) at the French "France Inter" radio channel largely contributed to the promotion of plant diet use in aquaculture.

Economic impact:

From an economical viewpoint, one major impact of these new feed formulations was the **limitation of the increase of feed cost, given that raw materials represent 60 to 80% of the feed cost.** As shown in the table, fish meal prices increased much faster (by a factor of 4.8) than alternative plant protein prices (like soybean meal which was multiplied by 3.3) between 1994 and 2014. The evolution of worldwide formulation of fish feeds between 2001 and 2011 given in figure 2 enables us to estimate how much the substitution of fish-based ingredients by plant-based ones has contained the increase of fish feeds overall costs. Table 1 below gives the multiplication factor in average formulation costs for 4 main groups of species worldwide. If formulation had not evolved from 2001, average formulation cost for salmon feeds would have been multiplied by 3, whereas with the incorporation of plant-based ingredients, that multiplication factor was reduced to 2.5 on the same period. For the calculation of global costs savings, plant protein was taken as soybean meal for marine fishes and shrimp and comprises of a corn gluten and soybean meal for the salmon and trout diets. Rapeseed oil and soybean oil (similar prices) were taken as vegetable oil sources (see sources of data at the end of that document).

The global fish feed production was 29.2Mt in 2008 (source: FAO). The global fish feed market was USD 24.6 billion in 2013 with a compound annual growth rate of 3.4% (source: Global Fish feed Market – Trends and Forecasts (2014-2020)). Cost savings related to change in formulation between 2001 and 2011 for these four species groups range from 13% for trout compounds to 21% for shrimp compounds. Data are missing regarding the cost reduction rate of carp compounds (which accounts for 29% of global fish feeds consumption in 2013). However we know that changes in fish feeds formulation for carp are very different from the 4 considered species group since carp is usually fed with feeds of lowest costs, FM being added only to boost their nutrient content. We thus consider an effect of the replacement recommendations on a global market of USD 17 billion. Global replacement of fish source by plant sources has then enabled to save between USD 2.9 and 4.8 billion in 2011 alone. This estimation is very conservative since without any change in formulation between 2001 and 2011, FM and FO prices would have increased more rapidly than they did, but our calculation does not account for this effect on the limitation of FM and FO price increase.

Considering that INRA used the trout as a model fish and performed most of its research on that species, the contribution of INRA to the global cost-saving related to trout feed is credibly substantial. **Global cost-savings of trout feed formulation** (a commonly grown species in Europe, considered by FAO to account for 3% of global fish feed consumption in 2008) reach USD 0.8 billion in 2011 and **USD 8.1 billion (7.2Mds€) cumulated on 2001-2021** (based on €value 2001).

	Actual cost in 2001				Actual cost in 2011					Cost in 2011 if formulation did not change since 2001				Actual factor of multiplication 2001-2011	Factor of multiplication 2001-2011 if no change in formulation	Percentage of decrease in 2011-fromulation costs thanks to change in formulation
Ingredient	FM	FO	PP		FM	FO	VO	PP		FM	FO	PP				
			Corn gluten	Soy bean				Corn gluten	Soy bean			Corn gluten	Soy bean			
Prix USD/t	555	300	275	183	1330	1750	1500	600	400	1330	1750	600	400			
Salmon																
Proportion of ingredients in formulation (%)	40	25	21	14	12	12	18	35	23	40	25	21	14			
Cost of ingredient (USD/t)	222	75	58	26	160	210	270	209	93	532	438	126	56			
Cost of compound (USD/t)	380				941					1152				2,5	3,0	18%
Trout																
Proportion of ingredients in formulation (%)	35	15	20	30	10	10	15	26	39	35	15	20	30			
Cost of ingredient (USD/t)	194	45	55	55	133	175	225	156	156	466	263	120	120			
Cost of compound (USD/t)	349				845					968				2,4	2,8	**13%**
Marine fish species																
Proportion of ingredients in formulation (%)	40	15	0	45	15	10	10	0	65	40	15	0	45			
Cost of ingredient (USD/t)	222	45	0	82	200	175	150	0	260	532	263	0	180			
Cost of compound (USD/t)	349				785					975				2,2	2,8	19%
Shrimp																
Proportion of ingredients in formulation (%)	25	2	0	73	10	2	0	0	88	25	2	0	73			
Cost of ingredient (USD/t)	139	6	0	134	133	35	0	0	352	333	35	0	292			
Cost of compound (USD/t)	278				520					660				1,9	2,4	**21%**

WORLD (all species)

Total market aquafeed 2013 USD	2,4E+10
Compound Annual Growth Rate	0,03
Total market aquafeed 2011 USD	2,3E+10
Global savings 2011 for all species if 13% cost reduction (USD)	**2,9E+09**
Global savings 2011 for all species if 21% cost reduction (USD)	**4,9E+09**

WORLD (TROUTS only)

Share of trout in aquafeed global market	2,70%
Global savings 2011 in global trout formulation (USD)	5,4E+08

Since there are few research dedicated to marine species worldwide, INRA's research results on trout have often been transferred to marine species feed formulation in France (source: CIPA). Thus, INRA's French impact on formulation change for trout and marine species feed produced and consumed in France between 2001 and 2021 result in 54M€ of cost-savings (2001 €value). That figure is an insight into the economic impact on the French aquaculture sector. Since half of French aquafeed production is exported, INRA's research credibly influenced the formulation of twice as much aquafeed, resulting in 109M€ of cost-savings cumulated in 2001-2021.

A major economic impact is also observed on the stability of fish feed formulations costs. Plant ingredients are much more stable on an annual basis (see Figure 3 below) than fishmeal. But above all, the use of plant proteins increased the range of possible ingredients available for formulation. A broad diversity of plant ingredients can now be used in fish feed: more than 50 potential ingredients, as compared to a dozen well characterized in the 90s, when fish meal ingredients were cheaper, less scarce and plants incorporated in fish feed formulations at a much lower level. Thus the potential utilization of plant ingredients in fish feed has improved the flexibility of the formulation and offered more solutions to control and optimize feed cost which is highly dependent on ingredient cost.

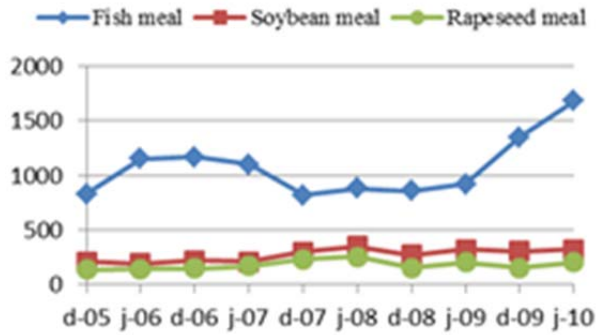


Figure 3: Evolution of the price of soybean meal and rapeseed meal in comparison to that of fish meal over 2005-2010

Benefits were observed at the level of feed producers that have seen their production of fish feed increased but also at the level of fish farmers since feeds represent more than 60% of their production cost.

Utilization of new ingredients in fish feed also contributed to the development of the industrial chain of feed production with a recent increase in incorporation of plant ingredient produced in Europe and a lower utilization of FM and FO mostly originating from South America (Peru and Chile).

Impacts 2

Global food security

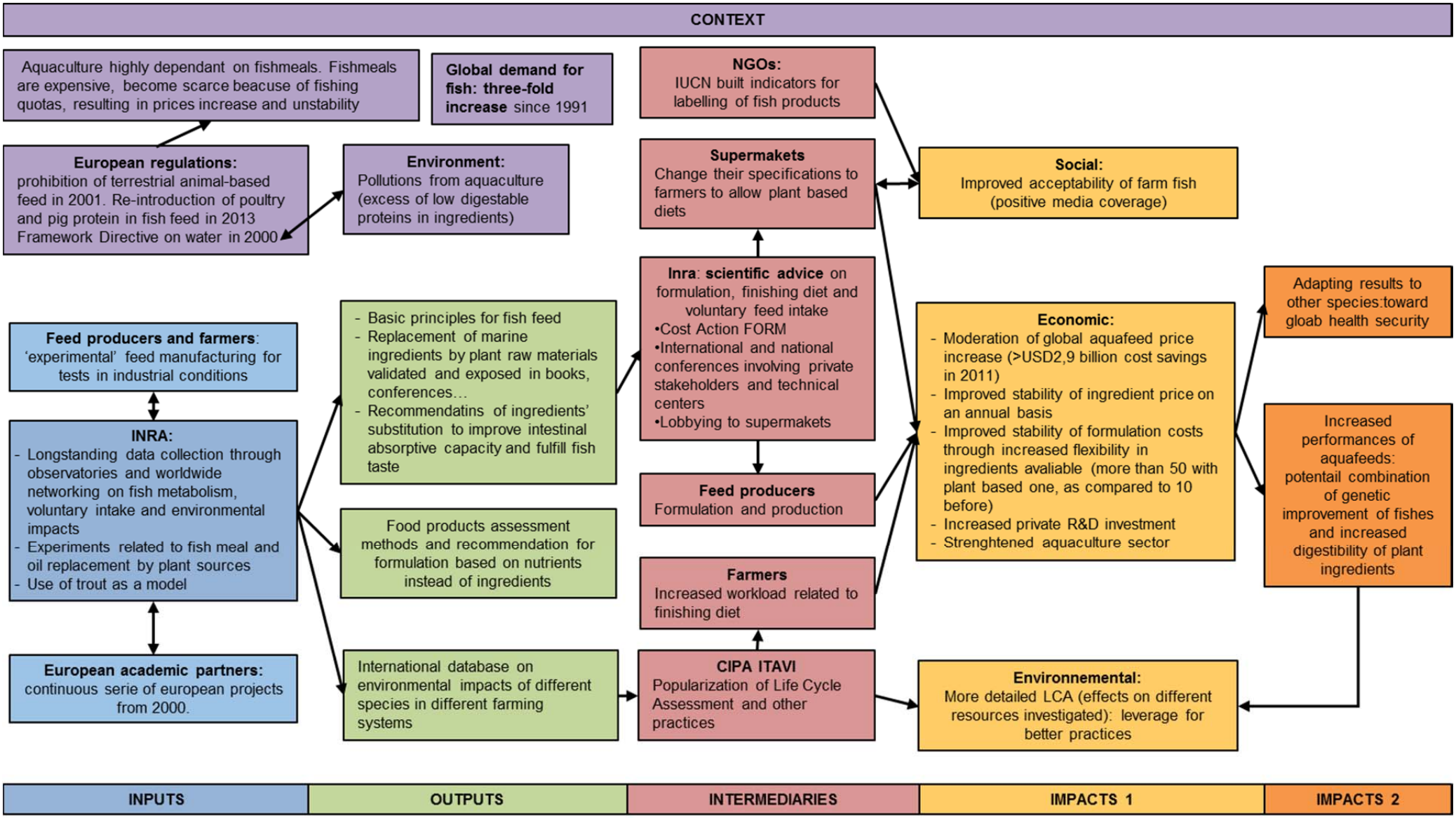
The modification of feed formulation for European fish species (mainly Salmonids) has positively affected the formulation of feed for **warm-water fish species** including carp and catfish that are the most produced species worldwide. Whereas salmonids depends entirely on a complete feed, much of the production of cyprinids has been based for a long time on less processed feed based on ingredients locally available (bran + oilseed meal) in addition to the natural productivity of the ponds. However, production of these species has become more and more intensive, by additional use of more complete feed leading to a better coverage of nutrient requirements. In some species, production has been increased from 2 to more than 15 tons/ha/year depending on the fish density and utilization of compounded fish feed. Although omnivorous fish species have lower dietary protein requirement,

they can severely affect fish meal demand due to their large volume of production (more than 80% of the aquaculture production). According to the FAO data, among the 29.2 Mt of feed fish produced in 2008, more than 70% were dedicated to fish species reared in Asia (carp, shrimp, tilapia, catfish…). Participation of Indian researchers in the AQUAMAX project in close collaboration with INRA scientists enhanced dissemination of results leading to evolution of the feed composition for Indian major carps.

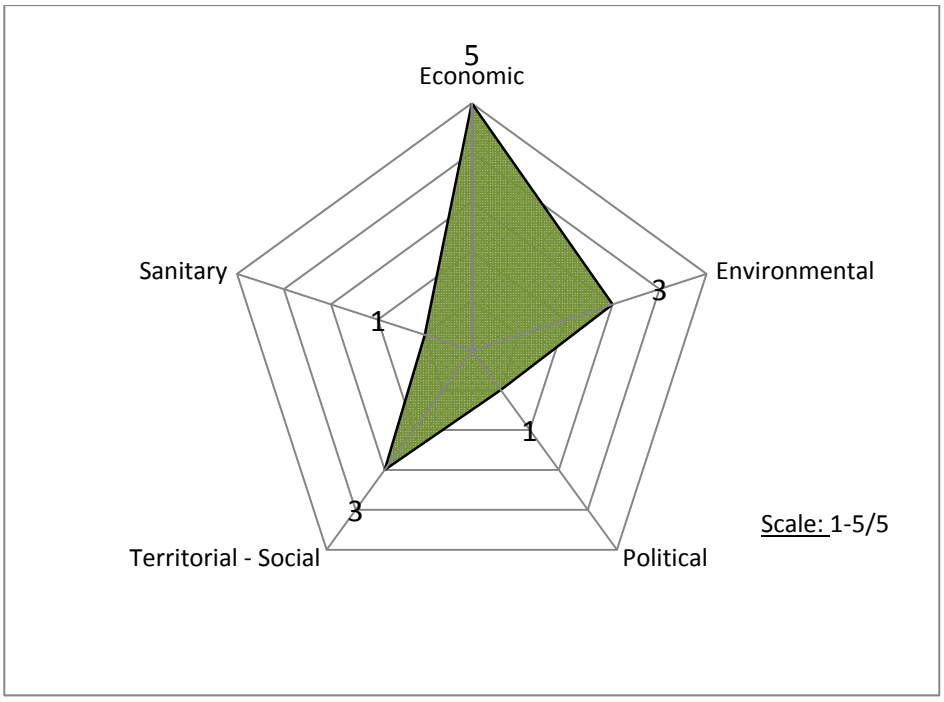
Potential impact on biodiversity

Genetic adaptation to dietary environments is a key process in the evolution of natural populations and is of great interest in animal breeding. The VEGEAQUA FUI-funded national project (2009-2013) demonstrated that survival rate, mean body weight and biomass can be improved in rainbow trout and see bass after a single generation of selection for the ability to adapt to a totally plant-based diet. This discovery has markedly affected practices in fish genetic selection especially in rainbow trout.

Impact pathway



Vector of impacts



Impact dimension	Importance	
Economic	5/5	- Moderation of the increase in feed ingredients' prices. Change in formulation between 2001 and 2011 to incorporate plant ingredients resulted in cost savings of 2.2 to 3.7 billion USD worldwide in the year 2011 alone - Improved stability of ingredients' prices on an annual basis - Improved stability of fish feed formulation costs through increased flexibility in ingredients choice (> 50 ingredients including plant based one, ~10-15 before) - Strengthening aquaculture sector fish feed=60% of farm costs
Environmental	3/5	Reduced reliance on natural marine resources More detailed and robust LCA: leverage to reduce environmental footprint and orientation of the nature of environmental impacts
Social-Territorial	3/5	Supermarkets acceptance pushed offer of veg fish Positive media coverage of veg fishes in general audience (Libération, Le Monde, France Inter). Improved acceptability of the transition from "carnivorous" fish to veg fish Contribution to fulfil global fish demand and food security

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