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Sustainability in Aquaculture: designing for the future

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Preface

Aquaculture, including the production of aquatic biomass, is a sector with a high potential. The demand for seafood and other products from the sea is increasing, whereas ecological constraints put a limit to the possibilities of gathering fish and other organisms by traditional methods. The production of fish and other aquatic organisms in controlled environments, as is practised in aquaculture, offers great opportunities. These activities can only be sustainable, if they meet economical, ecological and social demands. In view of these demands, drastic changes in the present-day systems of aquaculture are necessary. In this context, Innovation Network Rural Areas and Agricultural Systems in cooperation with the Fish Culture and Fisheries Group of Wageningen University developed a process for designing alternative, sustainable systems for aquaculture, possibly in combination with other functions. This process, described in this report, consists of an internet discussion, a number of design workshops around specific themes, concluded with a conference. Due to the international character of the issues at stake, the process aims at involving different parties around the world.

On a national scale, Innovation Network has developed alternative strategies for sustainable exploitation of natural resources of the sea and coastal zones[1]. The outcomes showed new ways for combining aquatic biomass production with energy generation, coast protection, recreation and other functions. The workshops brought together different worlds: aquaculture, agriculture, energy, water management, off shore etc. The usefullness of this approach was recognised by companies, public administration, researchers and societal groups. This was a source of inspiration for the set-up of a similar activity on a worldwide scale, which is presented in this report.

The report presented here discusses different present-day systems of aquaculture around the world, and their implications in terms of sustainable development. From this analysis, it is concluded that new systems are needed urgently. Next, a portfolio of activities is described, aiming at the design of new systems. The activities include workshops, internet discussions and a concluding conference. The proposed workshops should lead to alternative systems of aquaculture on land, in coastal zones and in open oceans, with an open eye for relations with other functions. Not only the technical aspects of new systems should be considered, but also the necessary regulatory and livelihood aspects. The total costs of the presented portfolio of activities amount to half a million euro over a period of nearly two years. On the basis

[1] See Ocean Farming report "Zee in zicht. Zilte waarden duurzaam benut", STT/Beweton and Innovation Network, ISBN 90-8044-968-7, The Hague, 2004.

of this document, various organisations (a.o. FAO, European Association for Aquaculture) will be requested to contribute.

I trust that this new format of activities contributes to the development of more sustainable aquaculture systems around the world. Even more important is the new dialogue among the stakeholders that may arise from the carefully designed cocktail of activities. This dialogue does not aim at analysing, explaining and convincing, but at building new systems, using various types of knowledge and learning by doing.

Dr. G. Vos,
Director of Innovation Network
Rural Areas and Agricultural Systems.

See also “Marine parks: sustainability at sea”, Innovation Network, report no. 04.2.070E, The Hague, august 2004.

Contents

Executive summary

Introduction

Aquaculture is at a crossroads, and has some large hurdles to take to come of age in the twenty-first century. As the Economist of 9 August 2003 put it: *"Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism and home-owners as well as environmentalists for access to the coast. Agriculture had the luxury of being able to pollute and alter the landscape first and worry about the consequences later. Not so aquaculture. Nevertheless, there is no sense in expecting modern aquaculture to emerge immediately as a perfect food supply that pleases everyone from animal lovers and greens to economists and industrialists. The challenge will be to regulate it prudently and efficiently, not just in the rich world but in poor countries and eventually farther out to sea, too"*. Sustainability issues rank high from whichever angle the development of aquaculture is approached. For aquaculture to be the answer to the global demand for fish, in a healthy diet for the rich and to feed the poor, it has to conform to present day ecological, societal and economic demands: the blue revolution needs to be green as well. But the rate of increase in global aquaculture production is slowing in many parts of the world. Perhaps this is due to production limitations, in which case current technologies may not suffice or be used very well. Fundamental innovations in aquaculture technology then would be needed. But, there could be other, societal, limitations as well.

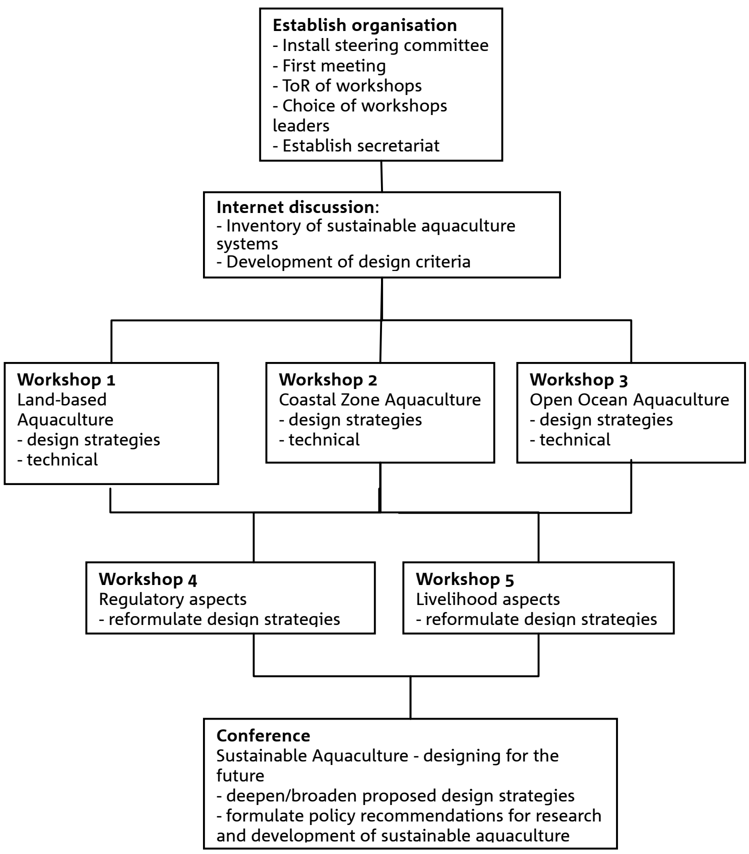
To investigate the present limitations to the development in aquaculture and to explore the innovations needed, the Fish Culture and Fisheries group of the Wageningen University Research together with Innovation Network Rural Areas and Agricultural Systems developed a series of design workshops followed by an international conference dealing with the question

- How can aquaculture be sustainably integrated in the vulnerable aquatic natural world in an ecological, social and economic responsible way and live up to its promise of a blue revolution?

A prospective analysis of future challenges in global aquaculture is essential as a basis for setting research and development agenda's. We intend to provide a forum for the development of a long term view through the process of designing sustainable aquaculture systems and practices. The Netherlands and in particular Wageningen University obtained quite some experience with similar discussions both around intensive animal production systems and food security, and with that has something to offer to the aquatic production sector. The starting point of the discussion on sustainable aquaculture designs will be the technical possibilities and limitations of present day aquaculture systems, while the pitfalls of industrial agriculture development of the previous century should be avoided. A variety of international expertise – within, adjacent and outside to the aquaculture profession - will be brought together to learn from each other's insights. The proposal was developed over the past year in a feasibility study and now entails a three pronged process that is to be executed over the course of one year. The process to arrive at sustainable aquaculture designs in a people, planet profit context encompasses respectively:

- an inventory of sustainable aquaculture systems and the development of design requirements design through and internet based discussion,
- a series of five separate workshops. Three workshops have a technical scope and treat the three main spaces in which aquaculture takes place (land, coast and open ocean). Two subsequent workshops deal with regulatory and livelihood aspects. Each workshop is required to develop one or more sustainable designs and design strategies, whereby the latter two workshops are to scrutinise the technical designs as well.
- concluded by a conference provisionally titled "Sustainable Aquaculture – Designing for the Future", to broaden and deepen the proposed design strategies and formulate policy recommendations for research and development.

The workshops result in a number of essays. Workshops and conference results will be published in a book and a policy brief. The figure below summarises the process.



Overall objective

Goal

The goal of the workshops and conference is to formulate a long term view and to generate new designs on the sustainable integration of aquaculture in the vulnerable natural aquatic world, and with that aid in setting research and innovation agenda's for aquaculture development.

Strategy

Tackling this goal is by nature a cross-disciplinary and multi-stakeholder task. Where economic, socio-cultural and regulatory aspects are defining the outcome of the competition for space, society also requires an ecologically sustainable aquaculture. Sustainability requirements can be envisaged as design requirements for which solutions are to be found from a variety of disciplinary and societal viewpoints. The strategy of the workshops and the conference will be to think in terms of design requirements, design strategies and actual designs for aquaculture systems that will meet criteria of different stakeholder interests: environmental, food security, animal welfare, water conservation, coastal protection, healthy and safe food, etc. Following this strategy will enable different stakeholders to reconsider the current somewhat entrenched positions in the debates around sustainability in aquaculture.

Result

The result of the series of workshops and conference will be

- a set of design strategies developed from technical, regulatory and livelihood viewpoints for geographically different aquaculture systems that will aid in the formulation of recommendations for research and development agenda's both at policy level and to the industry;
- a book summarising and presenting the discussions and the outcome reached in the process through a series of essays and design proposals;
- a policy brief that will summarise the recommendations for a wider audience.

Organisation and participants

- A steering committee aided by a secretariat to be set up in Wageningen will set the terms of reference and choose and invite two initiators for each of the workshops. These are subject specialists. Other tasks of the steering committee are to organise the internet based discussion and to set-up the final conference
- The initiators of each workshop will write a position paper and, based on the ToR invite other participants from various stakeholders in the field and interested outsiders.
- All workshops have a two day duration and will result in designs and design strategies to be reported to the conference

- The concluding conference re-examines the designs and design strategies and concludes with a formulation of research and development recommendations directed at policy level and the industry.

Costs

Budget summary by work package:

1. Management and co-ordination (steering committee; secretariat)	€ 47,048
2. Internet discussion	€ 44,800
3. WS Land-based aquaculture	€ 50,013
4. WS Coastal and riparian aquaculture	€ 50,013
5. WS Open Ocean aquaculture	€ 50,013
6. WS Livelihood redesign	€ 50,013
7. WS Regulatory redesign	€ 50,013
8. Conference	€ 158,085
Total proposal	€ 499,998

Financing proposal

Different approaches to funding can be made: each of the elements in the design process could be financed separately, or the proposal can be financed as a whole. The latter is the preferred option as goal and process can be guarded better. In discussions with potential financiers who were interested in partial financing, this became very clear: work of the steering committee and secretariat will be much more demanding in case of partial financing.

Work packages to be financed in full:

1. Steering committee and secretariat
2. Internet discussion, organisation
3. Workshops (a. Land based, b. Coastal Zone; c. Open Ocean; d. Livelihood; e. Regulatory)

Work package for which partial financing is sought:

4. Conference; it can be expected that the conference will have to be fully funded for those participants that are invited to contribute other participants will pay a conference fee;

Aftercare

5. Printing costs of book – financing proposal with FRONTIS. Costs of printing can be (partially) recovered by sale.
6. Policy brief – printing and dissemination costs to be covered in full.

To reduce costs workshops can be held preferably as part of already organised conferences and workshops. NUTRECO, the FAO and the European Aquaculture Society have shown interest in this construction.

Time schedule

Work package		Year1											Year2												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Secure funding		X	X	X																					
WP1 Committee				X							X						X								
WP2 Internet Discussion	Development	X	X																						
	Discussion			X	X	X	X	X	X																
WP3 Land based	Initiation	X																							
	Organisation		X	X	X	X																			
	Execution						X																		
WP4 Coastal zone	Initiation			X																					
	Organisation							X	X	X															
	Execution										X														
WP5 Open ocean	Initiation			X																					
	Organisation							X	X	X															
	Execution										X														
WP6 Livelihood	Initiation			X																					
	Organisation										X	X	X	X											
	Execution														X										
WP7 Regulatory	Initiation			X																					
	Organisation										X	X	X	X											
	Execution														X										
WP8 Conference	Initiation			X							X														
	Organisation										X					X	X	X							
	Execution																		X						
Aftercare	Book/Policy brief																			X	X	X	X	X	X

1. Introduction

Aquaculture is at a crossroads, and must overcome large hurdles if it is to come of age in the twenty-first century. This is the tenor of an article published in the Economist of 9 August 2003 (Appendix 2). The preceding editorial summarizes the dilemma:

> "Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism and home-owners as well as environmentalists for access to the coast. Agriculture had the luxury of being able to pollute and alter the landscape first and worry about the consequences later. Not so aquaculture. Nevertheless, there is no sense in expecting modern aquaculture to emerge immediately as a perfect food supply that pleases everyone from animal lovers and greens to economists and industrialists. The challenge will be to regulate it prudently and efficiently, not just in the rich world but in poor countries and eventually farther out to sea, too".

Regardless of how agricultural development is approached, sustainability remains a critical issue[2]. For aquaculture to meet the global demand for fish, both as a healthful dietary supplement for the rich and as a subsistence diet for the poor, it must conform to present-day ecological, societal and economic demands: the blue revolution must be green as well (Costa Pierce 2003). But regulating aquaculture alone may not be enough. In many parts of the world, the rate of increase in production is slowing. This may be the result of limitations imposed by current aquacultural practices, in which case fundamental innovations in technology may be needed (Funge-Smith and Phillips 2001). But other, societal, limitations could be at work as well.

To investigate the present limitations to the development of aquaculture and to explore the innovations needed, the Fish Culture and Fisheries group of Wageningen University, together with Innovation Network Rural Areas and Agricultural Systems, have developed a series of design workshops to be followed by an international conference dealing with the following question:

How can aquaculture be sustainably integrated in the vulnerable natural aquatic world in an ecologically, socially and economically responsible manner and redeem its promise of a blue revolution?

This report describes the development of the workshops and the conference, as presented in the proposal in Appendix 1.

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[2] Two of the five core sessions of the Aquavision 2004 conference to be held in Stavanger, Norway, organised by Nutreco, contain the word sustainability, emphasising a production-driven to a consumer-led form of aquaculture and achieving ways to ensure a 'licence to operate'.

The proposal was developed over the past year as a feasibility study in preparation for a three-day international conference. The conference goal is the development of new design requirements and new designs for aquaculture practices (Appendix 1). Due to the world-wide scope of the undertaking, it soon became clear that this goal was too ambitious to be achieved at a single conference. Instead, a three-step process is now envisaged in which various stakeholders in aquaculture will take part, and which will be completed within one year. With sustainable aquaculture design as the goal – sustainable understood in the triple-P sense (People, Planet, Profit), the three steps include:

- Using a series of internet-based discussions to develop an inventory of sustainable aquaculture systems and design requirements.
- Holding a series of five workshops: three will be technical, dedicated to the three environs in which aquaculture occurs (land, coast and open ocean) and two will be concerned with regulatory and livelihood issues. Each technical workshop will develop one or more sustainable designs which will be available for review by the regulatory and livelihood workshops.
- Concluding the process with a conference provisionally titled "Sustainable Aquaculture – Designing for the Future". The conference objective would be to broaden and deepen the proposed design strategies and formulate policy recommendations for research and development.

The workshops would result in a number of essays. Workshops and conference results will be published in a book and a policy report. The proposal presented in Appendix 7 was developed through (1) a series of discussions held at the Fish Culture and Fisheries Group with staff members, with Innovation Network Rural Areas and Agricultural Systems and with selected specialists, (2) an e-mail discussion with a number of aquaculture specialists around the world and (3) a literature and internet scan on current developments in world-wide aquaculture systems. The following chapters report on these searches and discussions. Chapter 2 reviews current developments in aquaculture, with an emphasis on the more technical aspects – a reflection of the authors' background and interests. Chapters 3 and 4 report on the development of arguments leading to the proposed format of the design process. Chapter 5 is concerned with feasibility and includes suggestions for financing the process.

2. Review

Aquaculture is often viewed as a single activity. But in reality it represents the aquatic counterpart of terrestrial agriculture, engaging in a broad range of practices and techniques and culturing a more diverse group of species. Many of the problems that frustrate environmental sustainability are common to both activities, and there are lessons to be learned from other food producing sectors. The Netherlands, Wageningen University, Innovation Network Rural Areas and Agricultural Systems gained much valuable knowledge from recent multidisciplinary and multi-stakeholder discussions on long-term developments in intensive animal production systems (De Wilt, Oosten and Sterrenberg, 2000) and on the issues of food security (Koning et al. 2001). The aquatic production sector can benefit from sharing such knowledge. On the other hand, this experience does not apply directly to aquatic environments. The debate over the sustainability of aquaculture is part of the international concern for "Ocean Governance". Within that context, the scope of the discussion is wide – covering issues that are both global and long-term and cross the borders that separate many different disciplines and practices. Central to the discussion is to develop a way of thinking about developments in aquaculture that will meet the criteria of different stakeholders and include such issues as environmental preservation, animal welfare, water conservation, and a healthful and secure food supply. A useful tool to guide thinking would be to develop practical proposals that take into account the social, legal and technical requirements surrounding sustainable aquaculture designs followed by a proposal for the actual designs of culture systems that conform to those requirements. The time scale set for the discussion is 25 years. Such a span is needed to put the process at some distance from the pressure of daily concerns and problems: freed from the immediacy of the present, the design process is then able to set its goals in the future, to open up new directions for innovative research and development. The questions are: what is needed technically, socially, legally and economically to reach desirable outcomes, and which future(s) would be most acceptable today? Which are the most realistic and likely to materialise into actual designs?

However, a useful starting point would be to take into account the technical possibilities and limitations of present day aquaculture. In order to obtain a feel for the huge number and variety of potential solutions, particularly those resulting from intensification, the balance of this chapter describes some current developments in aquaculture. With this discussion we hope to draw attention to the manifold problems associated with the assessment of proposed solutions for sustainability. Scale plays an important role in the debates on the sustainability of aquaculture and is important in thinking about innovations with a long-term perspective. We start off with considerations of scale.

2.1. Scale considerations

A long-term view of sustainability - what kind of aquaculture do we want for the future – must occur in the context of existing and potential aquaculture developments, increased population growth, increased consumption and changing consumption patterns of marine resources. It must also consider the impact of aquatic production on wild capture fisheries and marine resources[3]. Aquaculture's key role in the future food supply should be outlined at different scales including a global focus on the supply and scarcity of protein. At a *local scale*, systems that maximize resource use and minimize environmental impacts are to be designed. For instance, recent discussions at an international conference on integrated aquaculture – aptly titled "Beyond Monoculture" - put local issues at the forefront (Chopin and Reinertsen, 2003). Although this technical approach comprised just one part of a total sustainability framework – the "planet" part - the focus was on local technical solutions to sustainability that act on and become apparent over the wider ecosystem, on regional and global scales. A variety of open and closed system designs have been researched in detail to solve technical problems with integrated systems. However, during our discussions in preparation for this proposal, it was regularly brought to our attention that without giving due consideration to regulatory and livelihood[4] issues (including the incomes and welfare of workers), and without the development of educational, training and financial incentive approaches to transfer complex technologies from the research domain, many proposed solutions will not be viable (Troell et. al 2003).

Integrated techniques could facilitate environmental sustainability on a coastal *regional scale*: in this case the important issue is the long term environmental changes that result from increased aquaculture activities. Most studies on aquaculture's impacts have focused on obvious changes such as biogeochemical alteration of the sediment and the water column. But the ecological consequences from other factors, such as increases in background nutrient levels are poorly known, as are the impacts on natural biological production of longer term, larger scale changes in coastal morphology, the effects on genetic wild-stocks of their farm-raised counterparts, and the introduction of exotic species in new environments.

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[3] With kind acknowledgement to M. Troell, Beyer Institute, Stockholm who set me on this path in organising this section during an enlightening e-mail correspondence.
[4] to indicate social and economic perspectives at the scale of individual operators

The sustainability issues (design requirements) to be addressed are: what changes in ecosystem structures and functions - including the potential to generate different goods and services - are taking place; what are the results of increased aquacultural production in the coastal zone; and what direction should innovators follow to minimise unwanted impacts and maximise production?

Sustainability issues at the *global scale* return us to the longer time scale that started this section. It is not a choice of either fishing or farming to produce aquatic protein and foodstuff; the question is how to maximize the food production from both sectors in a sustainable manner. As there are many connections between fisheries and aquaculture, with causes and effects acting at different scales, these connections and scales need to be taken into consideration when formulating design criteria for sustainability, when devising associated research agendas, and when formulating best management practices for both aquaculture and fisheries.

2.2. Consideration of issues

To start at the global scale: since 1950 there has been a 100 percent increase in the per capita demand for fish products (Brown et al. 1998). Considering the growth in world population alone, predictions for the increase in annual world demand for fish are 150-160 million tonnes (FAO 2003). In the 1970's John Gulland estimated that 100 million tonnes was the maximum annual yield to be taken from the world's oceans. While fisheries reached this maximum early in the last decade, a decreasing trend in production is now apparent (Watson and Pauly 2001). Any additional increase must come from aquaculture, which is now the fastest growing primary food production sector, with an annual growth of around 9% per year since 1970, and with a present total volume of around 46 million tonnes of farmed aquatic products, 62% of which are animal products. In 2000, food fish captured by fisheries and grown by aquaculture represented 16% of the world's animal protein supply: 37% of this production was from aquaculture. Between 1970 and 2000 the production of cultured fish rose from a mere 5.3% to 32.2% of total fishery landings by weight. Per capita, this translates into a change in the supply of fish of 0.7 kg (0.6 kg excluding China) to 5.9 kg per annum (2.3 kg excluding China). Moreover, the proportion of reported marine capture fisheries that has been used directly for human food has declined from 80% in the 1950s and 1960s to about 65% in the early 1970s. The remainder is rendered into fish meal and oil used to raise cattle, poultry and fish (Garcia and Moreno, 2003; Tacon 2003).

Although most fish is still caught – including the fish catches for conversion to fish meal and fish oil, possibly within 20 to 25 years most fish and seafood will be cultured. Fish and fishery products have become the most international of all foodstuffs. At present, between 30% and 40% is traded on the global market (Valdimarsson and James 2001), and if supplies remain stable, there is little indication that this will change in the near future. However, while still the fastest-growing animal food production sector; growth in global aquaculture production is now slowing down from a high of 7.4% in the 70's, to 4.1% in the 90's[5]. This slowing of growth is attributed by some to market saturation and to problems with diseases, spatial and environmental limitations that afflict the major aquaculture producers (Funge-Smith and Phillips 2001).

But this scenario of increased demand for fish becomes more poignant if one considers that more than 70% of the earth's surface is water, while only 10% is useful for agricultural production. Before human population growth exploded, the amount of land available for agriculture was 20% of the surface. Given present agriculture practices, it could be argued that within a century only 5% will remain intact for agrarian use (Saeijs, ?). With world population still increasing along with a corresponding demand for food, structural problems will arise and new sources of food production must be found. The demand for more efficient use of coastal and marine environments will increase. Although many seas are over-fished (Garcia and Moreno 2003), marine biomass is underutilised. As a result, fishery practices and culture systems will increase. As a paper by Cury and Cayre (2001) would have it: "Hunting became a secondary activity 2000 years ago: marine fishing did the same in 2021". However, the design issues needed to facilitate this increase have many sustainability consequences:

1. The long term production potential and carrying capacity of ecosystems on which aquatic production systems would depend;
2. The availability of food and social entitlements for affected populations;
3. The resolution of complex land use issues in coastal and riparian zones;
4. The availability of scarce resources such as freshwater (Dugan 2003b);
5. The availability of employment opportunities and adequate incomes;
6. And last but not least, the aesthetic judgments that will play an important role in coastal planning.

Thus, when these broad criteria are considered as well, the demand for efficiency in the production of aquatic products is even higher than would be the case if it was based simply on the demands of an increasing population.

Aquaculture encompasses a diversity of system, species and management practices that can be classified into two types:

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[5] This is when excluding the Chinese statistics invariably obscures global trends

i. more traditional food aquaculture, mainly practised in Asia with a few species of freshwater and brackish water fish, shellfish and seaweeds, often practiced in polycultures and integrated with agriculture;
ii. and the more recent “business aquaculture” culturing, shrimp, catfish and salmon (Sorgeloos 2001).

The diversity ranges in a continuum from very extensive to hyper-intensive systems, a classification based on inputs and stocking densities (Zwieten 1998), executed in a wide range of farming systems (Funge-Smith and Phillips 2001):

- Water-based systems (cages and pens, inshore/offshore; marine, fresh and brackish water)
- Land-based systems (rain fed ponds, irrigated or flow-through systems, tanks and raceways)
- Recycling-systems (high control, enclosed systems, more open pond-based systems)
- Integrated farming systems (for example, livestock and fish; agriculture and fish in irrigation systems; mangrove-shrimp-fish systems)
- Enhancement systems, temporary holdings and grow-up systems (sea ranching; stock enhancement; tuna-fattening; various extractive shellfish cultures)

The two main types of aquaculture have begun to learn from each other's approaches (Sorgeloos 2001, Hambrey and Tanyaros 2003), Business aquaculture is adopting the principles of polyculture and integrated aquaculture as practiced in ancient Asian cultures; meanwhile, in China, Thailand and other important Asian fish-producing countries with a long tradition in aquaculture, the traditional pond cultures are mimicking business aquaculture by intensifying their operation. In the Asian regions there is a tendency to move away from culturing low-valued cyprinids “for the table” to monocultures of high-value species for “restaurants, celebrations and guests” (Li Sa-fe, personal communication). This change relies on an increase in the use of formulated feeds derived from fishmeal and fish oil. Serious changes in the world flows of fishmeal and oil will occur if this trend continues: Of the world fishmeal production used in aquaculture, China already consumes up to 30%, of which 60% is imported. An additional effect of this cross-fertilization of ancient poly-cultures and modern integrated cultures could be a further decrease in world fish production.

Free ranging aquatic organisms now being cultivated by man include a wide variety of taxa and species from different environments. Their specific biological characteristics and environmental requirements (Figure 1) induce the huge diversity in farming systems. At present there are no generic solutions for culturing new species, at least not within the current intensification paradigm that requires a partitioning of all components so as to optimise each. The consensus among aquaculture specialists is that species diversification is not a research priority - especially with carnivorous species - mainly because of the duplication of research effort required to address each species separately (Sorgeloos 2001). However, despite this research perspective, world aquaculture practice has found practical solutions: the number of cultured species (fish and shrimp) is now up to 262 according to some sources - between 2 and 10 times higher than in the 1970's, and it occurs in different parts of the world - including Europe and North America (Tacon 2003).

An even higher diversity is found among the farmers: significant differences exist between aqua-farming systems or approaches and resource-use patterns, but also between the goals and ambitions of the farmers themselves. Local and regional issues of food security, the species used, and coastal and rural development drive diversification in aquaculture practices. At the same time, the impact of world markets could work in the opposite direction, by driving uniformity and standardisation. Finally, consumer preferences can have an important influence on the diversification of both wild products and cultured species. It is important that in developing design requirements, diversity of farming practices, ambitions of farmers, resource uses and consumer preferences are recognised and addressed. Thus, a search for innovative designs should include technical aquaculture requirements as well as ecological, regulatory and socio-economic considerations.

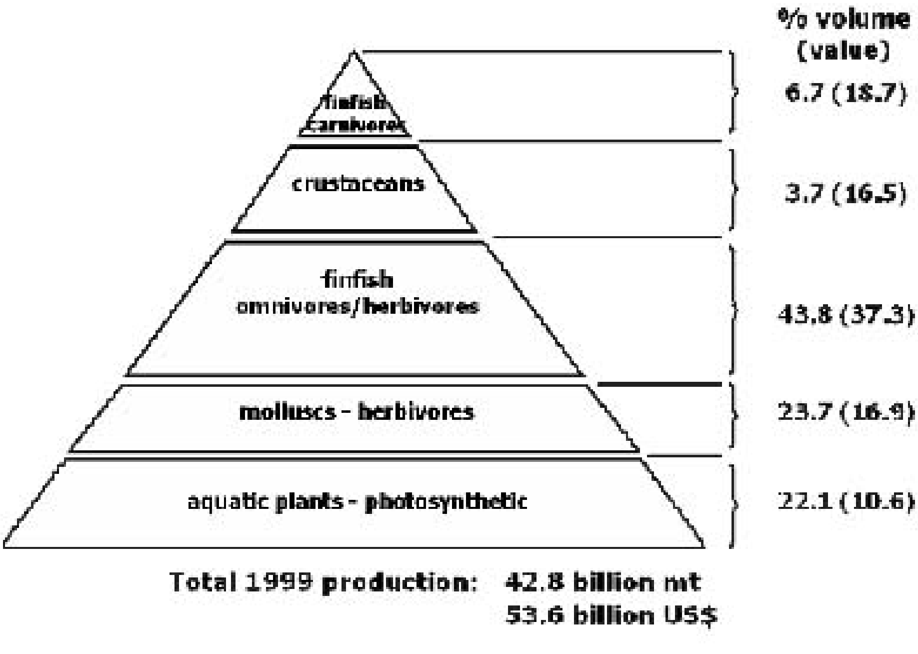

Figure 1. The relative contribution of major species groups to the global aquaculture production, according to their feeding habits in nature (Primavera 2002).

In the current debate on sustainability in aquaculture there is a tendency to focus on the environmental sustainability of salmonid and shrimp cultures, leading to attempts to control and regulate these cultures. As examples for potential developments of large-scale, aquacultures, they are highly instructive: both demonstrate the issues of sustainability played out at different scales. The growth of these well-publicised cultures has raised numerous concerns about intensification that are comparable to the issues raised with the farming of land animals;

- *local* - nutrient pollution that in some cases is comparable to that of small cities (Costa Pierce 2003); habitat destruction; landscape pollution;
- *regional* - vectors for invasive species and diseases; causes of genetic dilution of wild stock; changes in ecosystem productivity and fisheries production;
- *global* - the use of fish meal that makes some cultures net consumers instead of producers of fish protein (Folke et al. 1998, Naylor et al. 1998, Kautsky et al. 2000, Naylor et al. 2000, ICES 2002).

Figure 2 shows how the problems of sustainability interact and can be transferred from one scale to another. This example refers specifically to diseases in tropical shrimp cultures in coastal zone areas. Similar diagrams can be made not only for any other large-scale aquaculture system producing for (or extracting from) the world market, but also for smaller, more regional or local systems. The point is that innovative solutions to sustainability issues can take place at any level, but strategic choices for innovation require an awareness of the scale at which the issues arise. Conversely, the diagram can be used conceptually to position the proposed designs and their effects on different scales. Strategic designs then can range from technical solutions to inventive regulatory frameworks, but continue to require that solutions for sustainability problems are found at different scales.

When thinking about a strategic approach to the maximization of global protein production, an important question can be raised as to why so much research and innovative power is invested in carnivorous fish farming when nature provides viable alternatives. A related question is how these different alternatives can be designed and managed as efficiently as possible, given that they are interdependent. The extent of the global impact of aquaculture on natural ecosystems became clear in the debate on the use of fishmeal for fish feeds, which was in essence a discussion about a diversion of food from natural food chains and the resulting redistribution within the human food chain. But the solutions taken up by research and innovation are not self-evidently sustainable: for instance, the use of vegetable feeds, including components taken from agriculture production such as wheat, just represent redistribution from one human food chain to another. An alternative - again to harvest nature to feed fish but now using sources lower in the food chain - is the use of calanoid copepods, krill or mussels. This could be more promising, but again the ecological interactions of harvesting crustaceans - the basis of Arctic and Antarctic food chains on which birds, whales and other marine mammals depend, must be taken into account (Olsen 2001).

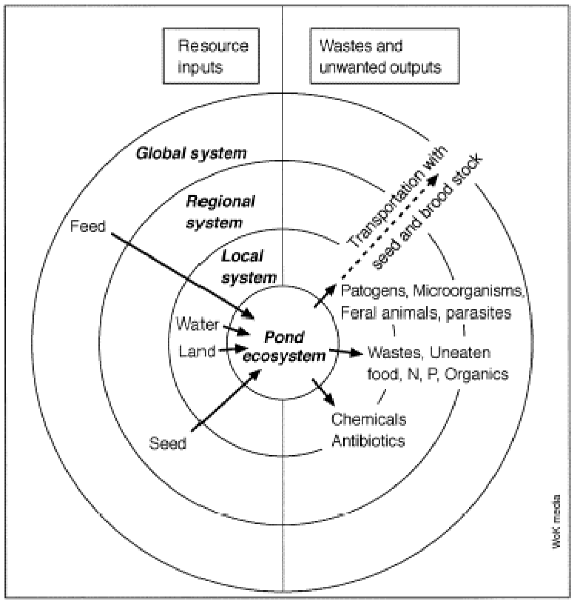

Figure 2. Interactions between shrimp farming and the environment at local, regional and global spatial scales; from (Kautsky et al. 2000).

The discussion could be taken a step further by investigating the idea of using primary and secondary consumers (shellfish, sea urchins, cucumbers, bagpipes, crustaceans, mussels and other shellfish) more directly for human consumption through approaches that increase the value of low-in-the-food chain products. Pauly's "fishing down the food web"(Pauly et al. 1998), a threat to natural ecosystems through fisheries, may then become a goal for aquaculture: "Culturing down the food web". Discussions on the use of foods produced naturally or cultured by industry for fish production should thus include such questions as:

1. How agriculture could succeed in finding alternatives to fishmeal, including approaches such as extracting fish oil from marine algae (Sijtsma, 2004);
2. What fish species are used in fish food production?
3. What is the status of these natural stocks?
4. What is the importance of these stocks for other components of the aquatic ecosystem?
5. What would be the result of ongoing intensification in global-protein production and what would be the corresponding impacts of increased world consumption of fish protein?

Lastly, alternative designs should also discuss questions as:

1. What would the increased culture of herbivorous aquatic species in the western world entail?
2. What impact could be anticipated from consumer preferences?

To approach this issue from a global perspective, design requirements for innovations require that the questions be analysed in conjunction, at a strategic level, and not in isolation.

In the international debate on aquaculture, too little attention is given to inland and coastal aquiculture systems that provide affordable food and a decent income to poor consumers (Bailey 1997, Graaf and Latif 2002, New 2003), even though aquaculture around the world, including in Europe and North America, remains primarily a small-scale family-based enterprise (Pillay 2001). The focus of the debate on the environmental sustainability of aquaculture is on salmonids, shrimp and other high-value carnivorous species including cod. However, the growth of the world population and the need to ensure food security will drive increased international trade and investment in large commercial farms – whether at sea, along the coast or on land – that may encourage more intensive production. The discussion of innovations in aquaculture must occur in the context of other human activities. In developing design requirements, top priority should be given to the nutrition requirements of the large segments of the human population who remain impoverished and the impact of this population on long-term global ecological sustainability and the innovations needed to achieve it. The type of systems analysis outlined earlier in this chapter could reveal the choices: how can aquaculture improve ecological sustainability while providing food and jobs for poor people around the world?

On a more regional level we can see that aquaculture system designs must occur in the context of more integrated forms of coastal and riparian zone management. Aquaculture itself may be seriously affected by water quality and habitat degradation caused by other activities. At the same time, it can also be the cause of environmental deterioration, affecting the interests of other users through habitat conversion and the pollution of receiving waters with nutrients, organic substances and potentially hazardous chemical pollution. Poor planning or siting of aquaculture operations may also result in self-pollution. Resource ownership, allocation of rights and related issues are often complex or ambiguous in the transition zone between land and water (GESAMP 2003). The interactions between various components of ecosystems and their use by humans are complex (Rosenberg, 2003), and a close examination is needed of the functions aquaculture could play when integrated in natural freshwater, coastal and marine systems. For instance, to return to this issue of species diversification: this may not be a research priority in the development of intensive cultural techniques, but other priorities exist: for example, conservation of endangered species (zoos, biodiversity parks) and discouraging the harvest of lucrative species in vulnerable coastal ecosystems such as groupers and plaice, which relates to both food and income security (Mous and Meyer 2003). The main function for aquaculture will remain food-production, but its importance in various other endeavours – nature conservation, recreation, water management, food security and the need for diversification – could increase.

Another example highlighting the changing function of aquaculture is in the various coastal shellfish cultures, particularly in Europe. Compared to the shrimp and salmonid cultures, concerns about shellfish, grazing, omnivorous fish aquaculture and marine algae, plant and seaweed cultures are fewer and of a more local and regional nature (Smaal 2002). In many traditional European shellfish culture areas new enterprises have developed, such as nature conservation and recreation, with the result that spatial extension of the cultured areas has been limited. Expansion of cultures still occurs, but only in non-traditional areas in France, Spain, Denmark and the Netherlands. In the Netherlands, the shellfish industry recognises this changing position and is re-examining their methods of operation. Though a recently published vision for the future of the industry is still very much within the context of their primary function, it is clear that a next step towards a more integrated view of their industry is within reach (Anon, 2001). Limitations on aquacultural activities resulting from the expansion of other coastal uses is apparently also an issue for the large Asian coastal cultures producing seaweeds and shellfish (e.g. Kleinen, 2004). Shellfish maricultures have been shown to provide vital ecosystem services in the removal of sediments and nutrients from the surrounding water, and seaweeds could have the same function (Olsen 2001, Sorgeloos 2002). Much work is now being done on the integration of fish, shellfish and macro algae cultures (Chopin et al. 2003, Hambrey and Tanyaros 2003, Hussenot and Shpigel 2003, Robinson et al. 2003).

By using plants and animals to control flows of nutrients as researched and practiced in both intensive and extensive and closed and open cultures, diversity and the performance of multiple functions plays a role in designing aquaculture systems that integrate with agriculture. With respect to open cultures, stock enhancement or sea-ranching (Welcomme and Bartley 1998, Howell et al. 1999) demonstrates that a synergy between fisheries and aquaculture can be maximised (J. Primavera, pers. comm.). Of course juveniles raised for wild stocking are produced differently from those produced for culture environments. Because most mariculture of shrimp or fish in ponds, pens and cages is capital intensive, it is in sea ranching (of fish, sea urchins, sea cucumbers and other invertebrates whose juveniles are hatchery-produced) that coastal communities can both reap the benefits of aquaculture and simultaneously conserve the environment, given that healthy wild habitats are prerequisites to sea ranching and the enhancement of stocks. When sea ranching and stock-enhancement technologies are combined with processes such as the creation of in situ artificial up welling, the local intensification of bottom-stirring and the placement of Fish Aggregating Devices (FAD), thinking about fisheries in agricultural terms such as sea-pastures is not far away (Olsen 2001, Vries et al. 2004).

Design requirements should address issues on a regional scale by taking account of changes in ecosystem structure and function that result from increased aquaculture production in the coastal zone. The recent history of mariculture gives evidence that it will develop irrespective of current constraints, such as competition for resources or adverse environmental conditions resulting from poor management of other coastal activities (Rosenthal 2002). More than any other activity using the coastal zone, aquaculture depends on good environmental conditions, including unpolluted waters and stable geomorphologic and hydrodynamic conditions. With the increase in aquaculture units, a corresponding increase in interactions with other stakeholders is to be expected. This suggests not only that mariculture adjust its environmental performance, but also that it defines its own needs for protection from the effects of inadequate environmental management by other stakeholders who in many areas have been allowed to use and pollute water resources with impunity. These include shipping with all its associated impacts on water; coastal cities with increasing population densities; habitat modifications for harbour development and electricity generation for air-conditioned cities. On the other hand, unintentional introductions through aquaculture can have long-term regional consequences that have yet to be studied in detail, though interesting work exists (Rosenthal 2002). Also important is the recently published account of the long-term effects of escaped farmed salmon on genetic wild stocks (Schiermeier 2003).

With respect to designing sustainable aquaculture systems, food security issues in Asia and Africa are now being undertaken with a more integrated “action-research” approach, where much more attention is given to the occupational needs of rural people. Africa is often considered a sleeping giant when it comes to aquaculture potential, but past failures in this technology that promised so much have led to, at least temporarily, a reduction in donor assistance. Failures are attributed to a compartmentalised approach of pursuing research followed separately by extension: this was the approach taken during most of the 70's and 80's (Dugan 2003a). Innovative approaches that give attention to livelihood needs are now providing a new impetus. Combinations of aquaculture and fisheries systems are developing “spontaneously” in many areas and are recognised as having more potential to address food security issues than attempts to optimise fisheries yields through more classical approaches. Examples are Acadja or brush park systems in West African lakes, the recent emergence of Fish Aggregating Devices in medium-sized lakes such as Lakes Mweru and Malawi (van Zwieten pers. obs.) and artificial reefs in Lake Malombe (Bell and Jamu, 2002) in southern Africa. The examples hint that the technologies offered until recently – mostly depending on pond systems with single species and with a requirement for the efficient use of land, labour and other inputs – may not fit African rural experiences where food production often depends on high labour input in mixed, extensive systems in highly variable environments. A major proportion of public sector research and development has been directed towards increasing productivity in pond systems, while very little attention has been given to improving the understanding of other production systems such as Acadja's, cages and culture-based enhancements and fisheries in floodplains, rivers and lakes. Innovations lie in a better understanding of a wider range of production systems, but must also include the development of feeds with inexpensive ingredients, genetic enhancements, choice of species (preferably local) and improved marketing (Jamu and Ayinla 2003). Designing technologies in accord with such experiences may even lead to a convergence with the popular wish in Europe for more “natural” production systems. But to achieve higher production from these systems may require even more technology, including biotechnology and information technology, than less (Bindraban and Rabbinge 2003, Jamu and Ayinla 2003).

As mentioned earlier, the convergence of food security issues and marine protection could lead to a more encompassing approach that views aquaculture as one of the essential functions of coastal development. A true aquaculturist tries to control all stages in a life cycle of a fish by prodding its physiology and controlling its feeding within a more (preferably) or less closed environment. The large aquaculture developments in Europe and North-America, following classical animal breeding scenarios, have been quite successful, and some are very promising (cod, sole); life cycles are then, it is said, almost closed. The investment in research needed to accomplish this is one of the main reasons for claiming that diversification is not a research priority. It will simply cost too much to do the same thing for all the potentially useful species that could be cultured. However, studying fish behaviour in the wild and using such information in a culture setting can be rewarding and innovative. In the Komodo island in Indonesia, groupers could be made to spawn in captivity in open-water cages by taking advantage of careful observations of spawning behaviour in the wild (Mous and Meyer, 2003). Perhaps the life cycle is not completely closed, but the systems may be more animal-friendly and potentially solve some of the wider sustainability issues by redirecting poor people from lucrative fishing in vulnerable coastal ecosystems.

2.3. Consideration of local spaces: Towards designs of aquaculture systems

As pointed out earlier, the types of existing culture systems and those currently being designed show differences in many dimensions: farming systems, intensity levels, species cultured, phases of culture (from hatchery to grow-out system), type and level of integration with other systems (natural or agricultural) and social practices and circumstances. In the previous sections we pointed out that when discussing sustainability, innovations, scale and context become important. For instance, strategic innovations in fish-feed technology for the present large carnivorous fish cultures could have enormous repercussions on the global use of fish-meal, and that could be part of the solution to the better management of some fisheries. But so could a focus on herbivorous species or cultures lower in the food chain (Olsen, pers. com.). In this section we will browse through a number of systems and designs that are on the cutting edge of new thinking and in various phases of implementation to demonstrate some of the variety - but also to highlight a few of the numerous problems that must be solved when designing new systems. Much technical research in culture systems is now devoted to three areas; offshore systems (sea-cages, sea ranching and stock enhancement), integrated systems and onshore controlled systems (in particular, recirculation systems). In the next sections examples are given for the first two systems. Examples for innovative use of recirculation systems can be found in the publications of the STT (Luiten, 2004) and in the work of the Fish Culture and Fisheries Group of Wageningen University. In discussions with specialists during this feasibility study, it was regularly pointed out that spatial planning issues (meaning fine-tuning with other users and overcoming legal constraints) are critical for further development of land-based systems and systems in more sheltered conditions in the coastal zone. In the next section we can only hint at these issues.

Offshore systems

Establishing requirements for a new culture system and defining them quantitatively is a very difficult task. For instance, Huguenin (1997) lists the decisions to be made when designing cage culture systems:

- site selection,
- mono or polyculture;
- species requirements;
- fixed floating, submersible or submersed and all technical design problems associated with each;
- source of fish seed;
- service and maintenance;
- scale;
- operational schedule;
- biomass loading;
- resilience to storms and inclement weather.

Solutions to operational problems are critical for the development of offshore mariculture systems (Muir, pers.comm.). Offshore conditions require that systems should be sufficiently self-supporting and can function without day-to-day surveillance. For instance, conditions on the North Sea are such that systems have to function automatically for five to ten days during stormy conditions. This means that the cultured species must survive completely from natural food sources or that advanced feeding systems which have not yet been invented must be used. Ideas to use the specific characteristics of the rough North Sea environment in conjunction with energy production abound (e.g. Ketelaars and Doepel, 2004), but have not been thought through as part of a design requirement for aquaculture purposes.

The increased demand for space in coastal areas is the force driving the siting of salmon cages farther to sea and into more exposed areas. Though the possibilities seem unlimited, many technical problems remain unsolved, problems that invariably require long-term, large-scale investments in research and development. The current trends in salmon cultures, but also in Mediterranean fish, are larger production units and a gradual shift to more exposed areas at sea. However, these are not yet “real” offshore systems, as feeding and surveillance are automated only in a limited way or not at all. Much research is directed to holding systems that can withstand the heavy conditions at sea. Developments in cage design are proceeding rapidly in Norway, Scotland, Ireland, US (Ocean Spar), Japan, and Taiwan. However, construction and operational costs remain prohibitive. The most important unsolved problem is the feeding system: how to automatically distribute food over the cage and store large quantities of it safely. Fish could live for sometime without food, but that means stress and higher mortalities, with a consequent decline in production. Another operational problem is the labour intensive cleaning of algal growth on nets of cages. In an operational sense no true offshore-systems exist: all known systems need daily supervision and in some cases divers are needed to feed the fish and clean the nets (Figure 3).

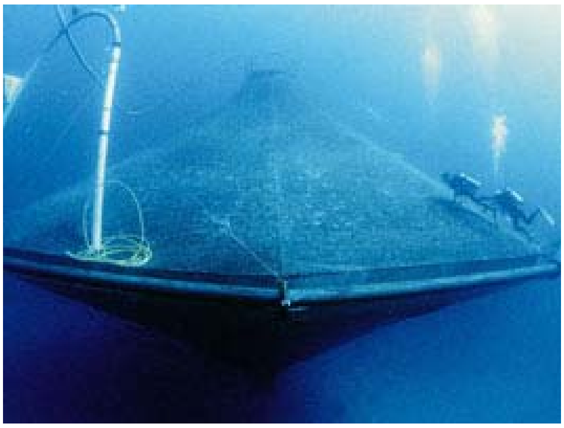

Figure 3. Left: submerged Ocean Spar cage, as used in Hawaii. Note the divers to the right over the cage. Right: the cage as used in the Gulf of Mexico project. This cage is equipped with a web cam and can be observed on the internet (photos taken from the internet, http://www-org.usm.edu/~ooa/).

Compared to current inshore cage systems, offshore systems impose limitations:

1. On the size of fish that can be stocked, meaning that grow-out systems on land are needed, considerably lengthening the operational chain.
2. On advanced techniques needed for sorting, handling and harvesting of fish.
3. On construction materials and operational procedures that are species specific, increasing development costs: there are no generic solutions, and for each species the wheel has to be partially re-invented, though experiences with existing systems and research pathways can be built upon.

Examples of building on earlier experience but with entirely new challenges are the development of recirculation systems for saline conditions and preparation of these systems for alternative species such as sole. Much has been learnt from the development of salmon cultures that can be used in the new cultures of cod, sea bream, sea-bass, turbot and sole (Kamstra, 2004), though each species has specific requirements in cage design.

The Gulf of Mexico Offshore Aquaculture Consortium presents an interesting research pilot in which many of the problems discussed in this paper are investigated. Most interesting is that the project is directed to the design and development of an offshore aquaculture industry in the Gulf of Mexico, and thus encompasses a multidisciplinary research effort where, in addition to technical aspects, economic, environmental, spatial planning, marine policy and legal issues are researched. The object of research is an Ocean Spar cage at a sea station 25 km from the coast near an oil-production platform (Figure 1). The site was chosen to avoid user conflicts, damage and vandalism. The oil company Chevron takes part in the project: the cage can be observed from the platforms, which also give passive protection against shipping movements[6].

Cage development takes place in the US (Ocean Spar), Japan, Norway and Scotland. In Chile offshore cages for salmon culture will be in operation soon. Large tuna fattening cages of up to 100 meters in circumference have been tested in Malta, Croatia and Turkey, and are being used in Australia. These are non-anchored free floating systems, in which fish of more than 50kg swim freely and without application of feed. Apart from harvesting little intervention is needed here, but considerable effort is needed to tow the cages great distances, sometimes more than 300km. Nevertheless, by 1997 tuna fattening – as this type of culture is called - had become Australia's most valuable aquaculture sector (Subasinghe et al. 2003).

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[6] For a good overview of the work done, refer to the internet site: http://www-org.usm.edu/~ooa/.

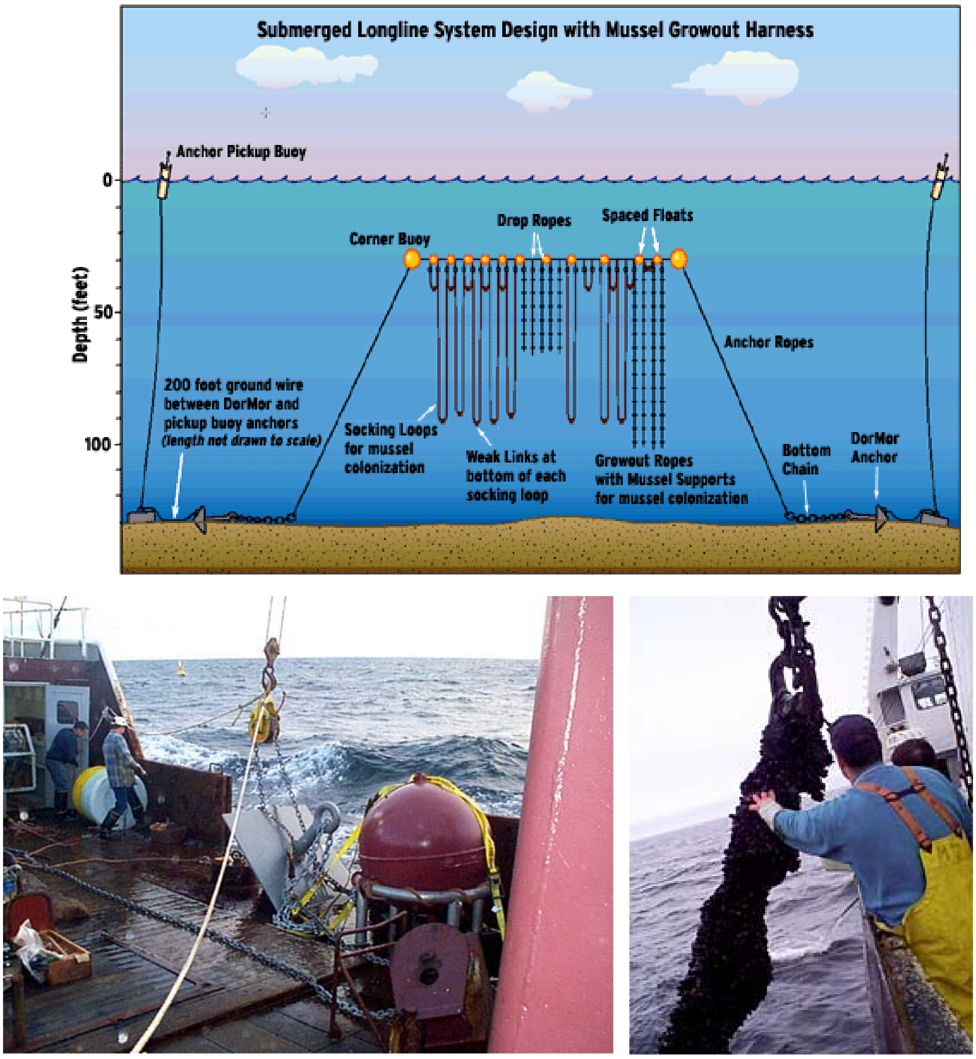

Figure 4. (Top): Mussel longline-cultures south of Cape Cod used in the SCOMAS project of the Woodshole Oceanographic Institute, Massachusetts (US). The longline is anchored and hung floating in midwater on underwater buoys to reduce damage by wave action. Various types of cables are hung from the longline, mussel seed is raised in special holding nets. All anchor-components are designed and chosen for durability. The upper part of the longline is lifted above the sea surface for inspection and during harvest. Floating capacity is adjusted when the growing mussels' weight increases. Separate surface buoys mark and protect the culture area. (Photo below left): Throwing out the longline. Shown are anchors, an anchor lifting buoy and a floating buoy. (Photo below right): inspection of the longline after 8.5 months. The 1.25 inch diameter longline is heavily loaded with a natural growth of young mussels embedded in hydroids (Drawing and photos taken from http://www.whoi.edu/science/MPC/dept/research/scomas_research.html.)

Offshore culture of mussels, oysters and macro-algae is attempted in many places around the world. For instance, the Woods Hole Oceanographic Institution (Massachusetts, USA), in cooperation with a fishing company, a long-line producer and a number of additional companies, researches the potential of a commercially viable mussel long-line culture. The research is a combination of offshore-engineering, biological productivity and bio-economic studies. To just give an impression of the type of work needed: designs must take into account protection against ducks and other birds, protection from the impact of surface conditions and protection against sea-stars from the bottom. Interactions with sea-mammals are investigated as well, in which case technical measures such as scaring devices are used. The main ecological research is directed at quantifying natural variation in spat availability (an oyster or similar bivalve mollusc in the larval stage), in particular to get rid of the expense of collecting and growing mussel-seed. The techniques of hanging cultures are long-known and used in many parts of the world (Australia, China, Greece, and the Netherlands): they are now being attempted in less sheltered areas offshore.

Similar research has been done in Germany by the Alfred Wegener Institute for Polar and Marine research in Bremershaven, which is attempting to grow mussel, oyster and algal cultures in the North Sea. Test systems are placed at 24 sites between Borkum and Sylt, near German areas of the North Sea where wind-mills are planned (Stolte 2004a). Depths range between 10 and 30 meters and the lines are hung between three and four meters beneath the sea surface. Different types of longline systems are tested for mussels, oysters and macro-algae. A main subject for research is the natural environment at the various sites: spat availability usually is not a problem, but spat fall on the lines is (Buck 2002). Similar systems have been in use for some time about 17 miles from Bremerhaven between the mainland and Helgoland. The company - Aqua Farms - is run jointly with the company Royal-Frysk[7]. Because mussels do not have to spend energy in removing sand and silt, and use all food for maintenance and growth, the growth rate is much higher than with bottom cultures. Culturing Laminaria, a red alga, is done successfully on rings that float at a five meter depth attached to a concrete anchor. Laminaria is harvested by cutting the algae from the ring: the remaining stem on the ring re-grows (Buck pers.comm.). The harvested part is dried and used to remove heavy metals from sewage.

Similar systems but with mixes of macro-algae and shellfish are conducted in various parts of China (Li Sa-fe, pers. comm.). Asian cultures of macro-algae are some of the largest in the world in terms of biomass produced.

Offshore systems for sea-ranching and stock enhancement are predominantly used in shellfish and lobster cultures. The Dutch and French mussel and oyster cultures are examples, but also the culture of *Pecten maximus* in France – all coastal cultures depending on a fixed substrate -, *Homarus americanus* in Canada, Ireland and Norway and the Atlantic salmon in Ireland. Canadian lobster culture and Irish salmon culture for stock-enhancement stopped as a result of better management of natural stocks (lobster) and bad economic returns (salmon). The most successful example of sea-

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[7] http://www.royal-frysk.de

ranching is the stocking of the red sea-bream (*Pagrus major*) in Japan. Young fish are stocked to replenish natural local stocks, grow for up to two years and are then fished just before the start of their migration to deeper waters (Welcomme and Bartley 1998). Around coastal New England (US), various research programs have been started to raise stocks of benthic fish-species by means of restocking with young fish. The results are to be published over the coming years. If the attempt is successful, the idea of raising sole on specific fishing grounds in the North Sea could become a viable option. Sole raised in recirculation systems are subsequently stocked in the North Sea, fatten naturally, and are fished when they reach a commercial size.

Integrated cultures

Current thinking on integrated culture design occurs mainly within the research domain, and is not yet based on active practice. Integration and ecological sustainability are seen as managing flows from subsystems within a closed aquaculture system or with more open aquaculture systems within a natural ecosystem. Only rarely are integrative aspects from more socio-cultural viewpoints taken into account.

Often a distinction is made between horizontal and vertical integration. Horizontal integration is found in a chain of hatcheries, nurseries and a variety of growing-out systems, where every part in the chain produces marketable products. For example juvenile sole is cultured in a hatchery, while “fattening” to consumption size takes place elsewhere. Vertical integration is currently the subject of much research: a recent conference titled “Beyond Monoculture” was devoted entirely to such systems (Chopin and Reinertsen 2003). In vertical integration, the waste of one system – heat, nutrients, and gasses - is used as input for the next. A renewed interest in the concept stems from concern for environmental sustainability: enhancing water quality, reducing waste and associated environmental impacts and generating additional crops. The integrative approach is a good step in the direction of a more inclusive, holistic or ecosystem-minded approach to the use of natural resources (Bogemans et al. 2004, Komen et al. 2004). Ecologically closed systems are the only effective way to deal with waste, and organic waste in fact should be viewed as a resource. From this angle, polycultures or integrated cultures can be seen as more than the linking up of components, or the joint rearing of more species. In fact they are concerned with the use and controlled intensification of natural carbon and nutrient cycles (Olsen, pers.comm.).

The objectives of integration of fish culture can be listed as follows:
1. Maximisation of nutrient use;
2. Maximisation of feed use;
3. Generation of valuable secondary crops;
4. Improvement of water quality for aquaculture;
5. Reduction of the organic pollution of water resources ;

6. Improved pest management.

The types of integration are:

- Fish polycultures (diversity of carps; sea bass and Tilapia);
- Animal polycultures (duck-fish; pig-fish: the classic Asian examples of farming systems that include a pond fertilised by duck or pig manure);
- Integrated pond or field systems, for example, rice with fish and prawns: a system that has been all but eradicated in many Asian rice growing areas (for example, in the Red River Delta of North Vietnam (Dang Van Thi, pers. comm.) due to the intensification of the rice culture with high-yielding varieties in combination with the use of fertilisers and pesticides. Another set of systems that draws much attention is integrated Mangrove aquaculture in Asia as a response to the destructions of the past three decades (Primavera 2000b, Costa-Pierce 2002);
- Integrated pond systems that make use of the natural growth of periphyton on poles in the water - currently under research in Bangladesh (Azim, 2001) - resembles rice-fish cultures;
- Cage fish with open pond fish: combinations of intensive and less intensive fish cultures: many Chinese freshwater cultures have one or two main species and a up to eight additional species. Usually such integrated pond cultures have a maximum productivity. Innovations are made by culturing species intensively in cages in ponds in which other species are cultured more casually;
- Shrimp with oysters; seaweed; oyster and seaweed; mangroves with fish and shrimp (alternating);
- Cage-open water systems: open water cage with fish and molluscs; or molluscs and seaweeds; fish and sea-urchins;.
- Closed systems: Fish with hydroponic vegetable growing; fish with algae.

In general most types of integration involve a combination of cultured stock (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed, shellfish), in which the wastes of one resource become a resource (fertilizer or food) for the others (Chopin et al. 2001), or where waste (periphyton: a complex matrix of algae and heterotrophic microbes attached to submerged substrata) is used as food for the fish.

After decades of destructive practices, interesting developments in shrimp cultures in brackish mangrove water areas are now taking place in many parts of South-East Asia. Integrated mangrove-aquaculture systems are now practised throughout the region, ranging from the traditional systems in Hong Kong and Indonesia, to the state initiated silvo-fisheries (integrated shrimp mangrove fisheries) in Indonesia. There are also mixed mangrove shrimp-fish farms in Vietnam and mangrove pens in Malaysia. Much attention is directed to requirements and functions of mangrove flora and fauna, cultured species, impacts of these on surrounding coastal fish and forestry resources, and the regulatory and ecological functions of the mangrove system in which the shrimp culture takes place (including nurseries, buffer zones, nutrient recycling, and wildlife habitat. (Primavera 2000a, Primavera 2000b, Costa-Pierce 2002, Primavera 2002).

In Asia is there is a tendency to move away from the integrated systems and poly-cultures that have been practiced for centuries. The reasons for this are the low value of the (carp and carp like) species that are successfully cultured in such systems; the absolute ceiling in amount of fish per unit of area that can be produced (Verdegem, pers.comm.); and problems associated with the intensification of the polyculture systems. Many current attempts to re-introduce and to promote integrated systems, mostly for environmental reasons, have failed, because generally fish are cultured for their market value and not for their productivity. Furthermore, management and marketing is complex and the return per unit of effort or unit of land is often reduced. Integration is seldom complete: often only part of the problem is solved. For example, molluscs remove particulate matter but regenerate dissolved nutrients which must then be removed by assimilation by algae for which huge areas of land are needed, Also, nutrient balances are not generally optimised for all components in the system, requiring fertilisation with nutrients that may be unavailable. The solution requires substantial management commitment. Resource use, management, marketing and economic issues must be thoroughly researched and explained before monoculture farmers will even think of moving to integrated systems[8].

More open systems - systems that interact with natural ecosystems - are attempted where salmon cages are operated next to Laminaria cultures (Chopin et al. 2003, Robinson et al. 2003; Stolte, 2004b) or other species. In these research-based efforts the additional cultures have value for local nutrient cycling: they could be part of one or more enterprises, with each specialising on one part of the system. Mixed farm integration may, in this case, be simpler – for instance, intensive farming enterprises can operate an as separate enterprise alongside mollusc and seaweed cultures done by others. Innovations are then required in coastal planning to achieve a balanced mix of complimentary enterprises which can be shown to benefit the wider environment (for example, by increasing water quality significantly). A Dutch example of mixed utilisation of coastal resources is the attempt to culture turbot with the waste heat of the Eems power plant, and the attempt to culture Ulva in a biofilter in Zeeland. In principle the possibilities are limitless, including water purification of intensive fish cultures by means of algae, copepods, artemias, mussels, oysters and halophytes. In Scotland, polycultures of salmon and sea urchins exist: sea urchins are not fed directly but live entirely off the feed not consumed by the salmon. At present much is being attempted on a research scale and sometimes on a pilot scale. In the GENESIS project (Hussenot and Shpigel 2003) sea bass is produced in combination with oysters and Salicornia in combination with recirculation systems, sedimentation ponds, foam removal and phytoplankton production. All components are directed at converting nutrients and organic material into useable biomass. The three main problems in such systems are:

1. Space: spatial requirements are high: 100 to 350 square meters of ulva per tonne of fish produced is needed. New areas should be planned explicitly to cater for such systems.
2. Technical: nutrient balances must meet the requirements of each part in the culture system.
3. Marketing: for each culture, specific management, quality and market requirements are needed, which makes integration difficult. Optimisation within one of the cultures in an integrated chain often means exclusion of preceding or following cultures; certification and quality demands from the market often reduce the viability of connections in the chain.

The economy is inflexible as well: why should Ulva be cultured on expensive soils if sea bass could also be cultured more intensively at the same location, while waste can be purified more cheaply in conventional purification systems?

A large number of algae can be cultured. NRLO has made an extensive study of the various possibilities of saltwater agriculture (Oosten en De Wilt, 2000). Those interested in such possibilities should read this report. With regard to the open sea cultures of macro-algae, the possibilities seem almost limitless, as can be inferred from the great Asian algal cultures (Guiry and Blunder 1991, FAO 1999).

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[8] see also: Bogemans et al, 2004 and Komen et al. 2004, who highlight these issues in the presentation of their ideas and designs of sustainable polyculture systems.

3. Development of the workshops: from scenarios to design

The proposal presented in Appendix 1 was developed during:

1. a series of discussions held at the Fish Culture and Fisheries Group with staff members, with Innovation Network and with selected specialists,
2. an e-mail discussion with a number of aquaculture specialists around the world and
3. a literature and internet scan on current developments in world-wide aquaculture systems.

During the course of these discussions, the original proposal to organise the conference around the hotly debated issue of fishmeal and oil use in salmon aquaculture described earlier was gradually expanded into the current, more global approach that has at its core the development of sustainable designs of aquaculture systems in three aquatic environments. This change of focus came about because:

- Debates on the issue of salmon culture were already being organised in the Netherlands and elsewhere (The European Trialogue in Brussels with Wout Dekker. CEO Nutreco; Simon Cripps Director Endangered Seas Program; WWF and Jörgen Holmquist, EC Director General for Fisheries, in February 2003; a discussion on the sustainability of cultured and caught fish, in particular salmon, in The Hague on 22 April 2003 organised by Schuttelaar and Partners, also including Nutreco; a workshop on the future of Salmon organised by ATO and ICIS, including representatives of AHOLD.) The debate that previously was carried out mainly within scientific circles is now part of a wider-ranging societal discussion. At this stage we did not see what our contribution could be without repeating much of the debate. We felt that a conference would not have much impact: moreover the issues are now placed in the wider context of sustainable practices as can be gleaned from the announcement of the Aqua Vision 2004 conference to be held in Stavanger, Norway.
- The focus on salmon was felt to be too narrow. In the September discussions prior to the start of the development process, it was argued that, to obtain more global impact, the tropical shrimp cultures should be included, as well as the marine cultures of the Mediterranean. However, the coastal shrimp cultures have been reported on substantially and exhaustively as well.
- In August the Economist published an article on the global challenges of present-day aquaculture titled “The promise of a blue revolution” (See Appendix 3). The article presented a comprehensive summary of the present state of industrialised aquacultures and pointed out that fundamental changes need to take place for it not to lose the “licence to produce” by taking the path of industrialised agriculture.

> The author argues that much can be expected from self- regulation by means of codes of conducts and certification concerning existing practices. Importantly, and curiously, technical and system innovation was not given much space, while we believe that much can be achieved here! In our opinion, the argument reflects the dominance of the large industrialised culture systems (salmon and catfish, soon to be followed by cod) and a limited view of the diversity, scale and potential of other aquaculture practices.

A more encompassing approach was felt to be needed, with a focus on technical and system innovation, which in the view of Innovation Network Rural Areas and Agricultural Systems can be induced through a design process based on sustainability requirements. But before arriving there a focus on the development of scenarios for sustainability issues was proposed. A similar approach had been taken successfully in an EU sponsored thematic network titled SEFABAR, in which some members of the research group of Fish Culture and Fisheries have participated and which was considered a highly instructive approach to sustainability problems. In the SEFABAR process, sustainable breeding goals for intensive land-based aquaculture systems were developed (Gamborg and Sandøe 2002, Komen et al. 2003). With the aid of scenario development, broad assumptions on developments in animal production were questioned with regard to which strategic directions for innovative research and development could be developed. Scenario building was adopted as a useful tool to order perceptions on alternative future environments in which today's decisions are being played out. In other words, both technical and socio-economic constraints that will steer developments can be evaluated, and the means to reach certain goals, given technical and socio-economic conditions, can be analysed. As we began our work with scenarios we began to formulate dichotomies that could be useful in developing them: the two most important dichotomies were (1) the culture of herbivores versus carnivores; and (2) closed cycles and cultures based on fishmeal and oil (salmon/clarias/trout/cod/soles) versus extensive cultures and open cultures that exploit natural productive capacities (shrimp/mussels).

Based on a quick scan of the internet and the general literature to investigate the idea, a letter was composed and sent by e-mail to a large number of people potentially interested in the process of developing the workshop (Appendix 4). The choice of people was based on an inventory by the programme committee with the main criterion being a perceived capacity to think broadly and an ability to produce innovative ideas in an enabling setting away from direct professional interests. In the letter the respondents were asked to give names of people who they thought would be interested. A selection of these individuals also received the letter via e-mail. Very soon it appeared that the circle in which names were sought and given was closed - no new names came up after just a few rounds. Most of the people referred to were to be found within the scientific world or the global administrative world. We received little reaction from the industry (practising aquaculturists, large aquaculture companies, the feed industry and system builders). This was to be expected because the scope of the proposed discussion appeared to be somewhat outside the immediate concerns of the industry. Furthermore the aquaculture industry only has a few large players that could be interested in the “long-view” discussion proposed. In a discussion with a representative of NUTRECO, our proposal for a discussion on the future of aquaculture that was outside the direct interest of the company (salmon, and the development of another aquaculture business based on cod) only received a lukewarm response. It became clear that NUTRECO follows its own innovation pathways. The letter, considered as an “appetiser”, asked for a reaction on contents, process and level of participation from the respondent. Many reacted positively, but somewhat expectant reactions were mainly on the process and not on the contents of the discussion.

We foresaw three themes on which a discussion on innovation should centre. In part these are problem areas, in the sense that strategic innovation can be expected to make aquaculture move forward; in part they are instigators of problems as a result of the societal demand on aquaculture:

- Ecologising aquaculture
- Ethololgising aquaculture
- Food security

In a triple P – people, planet, and profit – context, criteria or values that define sustainability can be developed for each of these themes. Innovation Network then pointed out that these criteria for sustainability also could be considered as design requirements on which sustainable designs can be developed.

In random order and without much reflection and depth, a number of design criteria were mentioned in the letter:

- diversity in cultured species;
- integration of production systems;
- the use of lower trophic levels for feed or food production;
- animal-friendly techniques;
- consideration of (human) cultural practices;
- recycling of nutrients;
- incorporation of aquaculture in coastal zones (“scenic aquaculture seascapes”);
- methods of conserving biodiversity and the resource base;
- food security framed in livelihood systems;
- “natural” production systems.

More design requirements could be mentioned, but we felt this to be our work only in as far as it would sharpen the focus of the conference; mainly this would be a major task for the participants in the design process.

In the reactions to our letter no examples of potentially interesting developments – outside those already known – were received. Given the highly dynamic nature of the industry, it can be expected that in many places in the world interesting innovations take place, either on paper or in practice, that fulfil some or many of the sustainable design requirements. However, we were unable to obtain a good overview. A project that was often invoked in our discussions was the "Ocean Farming" programme of the STT, now published (Luiten 2004). This project is typical of the type of endeavours we were searching for, but it was still only available in very rough drafts; though now most of it is published in Dutch. And most of the final outcome is still in the phase of radical ideas or in the domain of basic research, with many of the issues mentioned in our review still unresolved, due to the highly technical focus of the project.

Perhaps some ideas are already being developed in one form or another, but on a small scale without much fuss and without publicising their existence. Practical examples of "new" systems are there, but hard to find: for example, hydroponics; vegetable-cum-fish farms (in the Turks and Caicos islands, US and Canada); newly cultured species (many attempts at numerous places); and alternative programs for maximizing benefits from the coastal zone. To obtain a good overview of such examples more time and effort is needed than was available during the course of this feasibility study.

To structure the workshops and give them a more global context, the following approach was proposed:

i. Starting from a basic scenario (food production in the world, and in our case, the production of fish and other aquatic food products, will have to increase in year x by y times given increasing demand);
ii. Bottlenecks are to be defined (these issues are probably encompassed by the three main themes already mentioned);
iii. The bottlenecks under each of the themes lead to design criteria;
iv. Once defined, the designs or approaches to design are constructed.

In the next chapter we will discuss how this approach led to the final proposal.

4. Design: strategies

Discussions between the Fish Culture and Fisheries Group, Wageningen University and Innovation Network Rural Areas and Agricultural Systems led to a proposal to finance the current feasibility study modelled on a three-day conference and develop a work plan to arrive at the goals stated there (Appendix 4). During the first two days design requirements and new designs would be formulated and discussed. The third day would be used to discuss the results under the guidance of prominent members of the world aquaculture community, and to arrive at the formulation of research and policy ambitions. It soon transpired that the notion that we could complete the whole design process, including the soliciting of comments and the drawing up of policy conclusions in one conference, was too ambitious considering the world-wide scope of the undertaking. Instead, a three-pronged process spread over a longer period was proposed:

1. An Internet-based discussion;
2. A series of five separate workshops; and
3. A concluding conference, with time to write essays in between.

Sustainability requirements can be thought of as design criteria, and the assignment for the participants in the discussions and workshops will be to design sustainable aquatic production systems. To embed such an exercise in reality, but also to flesh out design criteria, the starting point would be existing systems that are thought of as sustainable or are seen as promising. One way to look at aquaculture is that it functions as part of the larger ecosystem and that it can perform more functions than food production. For example, it can be used to conserve fragile marine ecosystems. Another perspective is that aquaculture engages in nutrient recycling that could be performed within one closed, integrated system, but can also be seen at a larger scale in the context of coastal zone management. Aquaculture can be one part of a larger nutrient recycling framework, where nutrient runoff from land-based systems becomes input to a set of mariculture systems. Yet another perspective is that to have a licence to exploit open oceans or coastal areas (including rivers and lakes), it must be clear who has been granted such licence: regulatory aspects are a set of design criteria. Lastly, an important design constraint remains the production of an adequate food supply, not to mention the lifestyle and welfare of the producers: food security and employment need to be included in the design process as well.

An important force influencing aquacultural design came to the fore: the space available. An analogy to animal breeding systems on land is appropriate:

- Where space is expensive and relatively scarce, as in Northern Europe, intensive farming systems for pig and poultry have developed. This corresponds to the development of land-based or coastal zone aquaculture where high-cost recycling systems are required or, to escape the multiple demands of coastal zones or land-based systems, we have the example of high-cost open ocean cages.

- Where space is abundant, as in the Argentinean Pampas, an extensive system of cattle herding has developed. In aquaculture, this corresponds to the development of low cost, large scale cages (not yet existing) or to sea ranching systems (which do exist) on the open sea.

This geographic focus was used to further develop the workshops by providing a more practical focus on the design process. Three work packages of possible designs were envisaged:

1. Land-based aquaculture (including the present day, low cost, pond-based systems and high cost recycling systems and raceways)
2. Ocean-based aquaculture (usually high cost systems but also including the more extensive sea ranching and stock enhancement systems)
3. Coastal and riparian zone aquaculture that functions as part of a fragile ecosystem in a multiple use environment (including both high cost intensive systems and low cost extensive systems).

With its geographic focus this is almost a copy of the "ocean-farming" approach by the STT (Luiten, 2004). We felt that it could be useful to build upon what was learned during this process and to bring it further by focussing more on solutions to aquacultural production by assembling a group of people that have more experience in the problems and potentials of aquaculture than could be achieved in the STT approach. In particular, the additional focus on societal and regulatory constraints is considered highly valuable.

In a follow-up message sent to those who answered the first mail (Appendix 5), we requested examples of innovative designs or approaches that fulfil a number of broadly stated design criteria. The reactions to this request are incorporated in the review (Chapter 2). At this point our view was that a deliberate technological focus would be taken, and that regulatory issues would not be considered in full. The argument was that though issues of sustainability are to be approached in a triple-P context, in the end fish and seafood must be produced in or outside fish tanks at a certain location by people who nurture and harvest them. Innovations in technical aquaculture design are very much needed. The salmon model, based on intensive livestock farming, must be re-examined in terms of integrated design. And the shrimp model, based on an old-fashioned frontier notion that allows unrestrained reclaiming of coastal zones for food production, also needs rethinking. Both modes of using aquatic resources now have a rather bad press, at least in richer and more northern regions, and more integrated, sustainable designs are needed. Furthermore it was felt that to make aquaculture sustainable, too much focus has been placed on regulating the industry. Notwithstanding the present need to do so, the question may be raised as to how regulating, certification, following soft and tough approaches, or writing codes of conduct for aquacultural practices would necessarily lead to the technological innovation required to increase production sustainably.

We received a limited number of highly relevant and substantial reactions to the second mail. Telephone conversations with some of the individuals approached revealed that the limited number of reactions was mainly due to time constraints, while it was still unclear what could be expected of the process. Once again, reactions to the initiative were invariably positive. A strong feeling exists within the scientific community that the type of discussion that we proposed is highly relevant and timely. However, we received a strong reaction to the technological focus proposed, which was viewed as too limiting. We agreed: system innovations also entail innovations in the social and economic domains, and these must be catered to one way or another in the proposed workshops. But clear examples of where regulation has led to technological innovation must then be provided for discussion in the workshops.

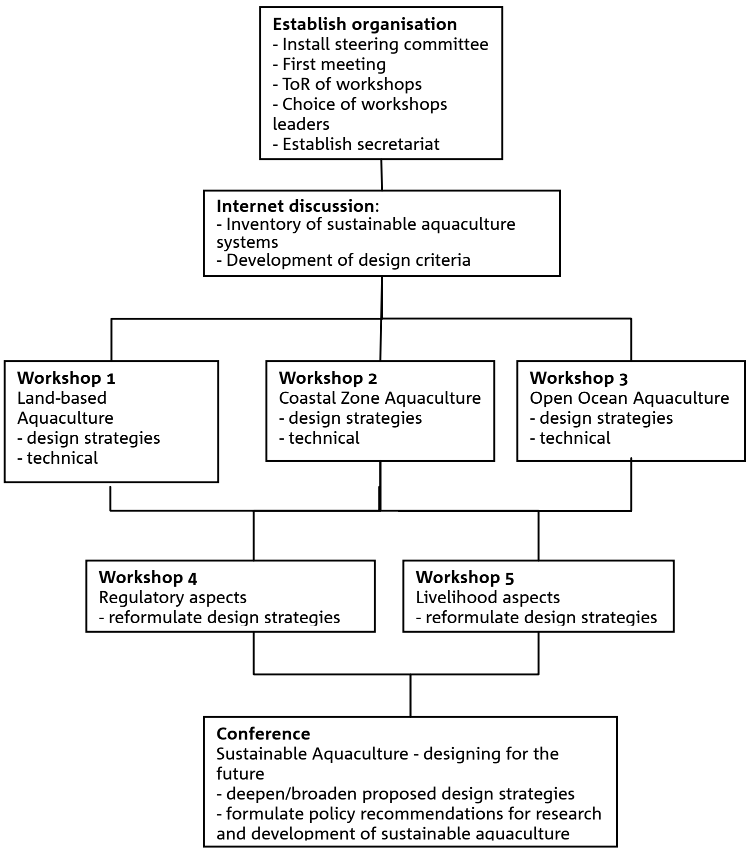

Figure 5. Flow chart describing the four steps in the design process: the internet discussion, three technical design workshops; two social and regulatory design workshops and a concluding conference (ToR = Terms of Reference).

More information on existing and promising sustainable designs can be anticipated from an open discussion platform; and for this purpose, an internet discussion site could be a most useful tool. The site to be developed would be used to obtain views on what is judged as technical innovation in aquaculture and what economic, social and ecological problems are solved as a result.

Finally, the proposal (Appendix 1) was built around the structure described in figure 5. During the course of one year, an internet discussion and five workshops will be held. The first three will have a technical focus, which will provide input for the last two workshops that will be dedicated to designs that include regulatory and social concerns such as employment and food security. The results emerging from these workshops are to be scrutinised during a concluding conference, organised along the same lines of the five earlier workshops - and a plenary discussion attended by all qualified (and invited) participants.

5. Proposals for financing

Different approaches can be taken: each of the elements in the design process (internet discussion, workshops and conference) could be financed separately, or the proposal could be put forward to be financed as a whole. Because it is less time consuming and more manageable, the latter is preferable. However, the former approach could be used to start off the process, if funding of the remaining workshops can be secured.

Initial discussions with potential funding sources indicated that financing the whole proposal may prove difficult: many were interested in only one or a few of the workshops, and up to now we have not been able to find funding for the whole process. Discussions have been held with Wageningen University (FRONTIS), the European Aquaculture Society, the Ministry of Agriculture, the Food and Agriculture Organisation and Nutreco. Innovation Network Rural Areas and Agricultural Systems expressed interest in co-financing part of the process as well.

From these discussions we learned:

1. It would be possible to finance a number of the technical workshops and to publish the final book or report.
2. All those who were approached found the proposal too broad, and had specific requests to focus the contents of the programme.
3. The total budget was considered excessive, and a number of solutions to reduce costs were proposed; these included:
   A. Reduce travel and hotel costs, link workshops to conferences so that the people invited will not have to travel twice.
   B. If the Food and Agriculture Organization is going to assist in organising the two latter workshops, are they willing to help pay the costs for participants from developing countries?
   C. Reduce costs by collecting a conference fee.

The budget presented in Appendix 1 gives an overview of the total costs. These can be lowered considerably if these and other solutions are taken into account. A number of respondents gave advice about additional sources of funding that will be pursued:

- The EU FP6 program;
- Because the project is global, Heinz, Rockefeller, Suzuki Foundation, or the MacArthur foundation could be viable options for seeking funds;
- The World Bank and The Asian Development Bank; there are probably other foundations as well that could be approached (most US-based);
- The industry itself, for example, “Norsk Hydro” (Norway);

- Ribbon.

The proposal will be put forward to a number of these potential financiers. Innovation Network Rural Areas and Agricultural Systems is willing to assist in finding funds.

6. Concluding remarks

The proposal needs further strategic focus on the actual substance of the various workshops. Aquaculture is a highly diverse undertaking, with a potential to grow in many different directions. Each of the workshops could itself be a theme for a conference, and choices will have to be made. The focus will be attained in discussions with various interested parties, and finally by the choice of people involved in the workshops. More thought needs to be given on how to present a good multidisciplinary mix. Involvement of the industry also needs more attention. Lastly, funding must be secured: to do so will take time.

A committee of recommendation is to be established to assist in promoting the proposal. Discussions with potential members have started.

We are confident that the proposal provides an excellent framework to start an innovative process aimed at the development of sustainable designs for aquaculture systems. This is confirmed by the invariably positive reactions received when discussing the initiative. This discussion is at the centre of the debate on using the ocean and freshwater space for food production sustainably: to turn the “blue revolution” into reality. We should take full advantage of this opportunity and not lose momentum!

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Appendix 1: Final proposal for a web-based discussion, five workshops and a conference

(Paul van Zwieten and Johan Verreth, Wageningen University and Jan de Wilt, Innovation Network Rural Areas and Agricultural Systems)

Contents

Background

Aquaculture is the fastest growing primary food production sector in the world, with an annual growth of about 10% and a total volume of about 46 million tons of farmed aquatic products, 62% of which are animal products. In 2000, food fish from capture fisheries and aquaculture represented 16% of the total animal protein supply: 37% comes from aquaculture. Considering the growth in world population alone, the demand for fish will certainly grow. Although most fish is still caught – including fish used for reduction to fish meal and oil (FAO, 2003) - within 20 to 25 years, when annual catches have stabilised at around 90 million tons, it is likely that most fish and seafood will be cultured.

The explosive growth has put the industry in a quandary neatly summarised in the following quote from an article published in the Economist of 9 August 2003:
"Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism and home-owners as well as environmentalists for access to the coast. Agriculture had the luxury of being able to pollute and alter the landscape first and worry about the consequences later. Not so aquaculture. (...) The challenge will be to regulate it prudently and efficiently, not just in the rich world but in poor countries and eventually farther out to sea, too..."

Issues of food security and food safety can be added to the dilemmas mentioned here:
- The perception of aquaculture as a form of bio-industry, with its negative connotations on animal health and environment versus the need to produce food for an increasing world population and meet the ambitions of aqua-farmers;
- The effects of intensification of aquatic food production in and around natural (and often vulnerable) aquatic ecosystems;
- Competition for space in the aquatic environment.

Sustainability issues rank high from whichever angle the development of aquaculture is approached. For aquaculture to be the answer to the global demand for fish – as a healthful supplement to the diet of the rich and as a subsistence diet for the poor – it has to conform to present day ecological, societal and economic demands: the blue revolution needs to be green as well.

But, regulations alone may not provide the answer. Despite the large apparent growth figures, the rate of increase in global aquaculture production is slowing in many parts of the world (FAO, 2003). There could be societal restrictions causing this. But the slowing of growth could be due to production limitations as well, in which case current technologies may not suffice. Aquatic systems inevitably are going to be used more and more for food production, though culture-based systems and aquaculture compete with other uses of water and aquatic space. Current practices in the modern large-scale fish and shrimp mono-cultures, but also the intensification of ancient land-based cultures, mean that integration at different scales – local, regional and global - is a key issue in the development of aquaculture systems. Aquaculture needs a fundamental transition from concentration on maximising output from the target species to integrated management of natural resources and the ecosystem. This requires fundamental innovations: new designs in aquaculture technology as well as in production systems, and regulatory practices that are ecologically, socially and economically sustainable.

The conclusion that the development of a long-term, innovative view on the future of global aquaculture is timely and needed is shared by many involved in the industry across the globe. A prospective analysis of future challenges in global aquaculture is essential as a basis for setting research and development agendas: the debate on sustainability in aquaculture is part of the international concern for "Ocean Governance". This proposal intends to provide a forum for the development of a long-term view through a process of designing sustainable aquaculture systems and practices. The Netherlands and in particular Wageningen University gained much valuable knowledge from similar discussions regarding intensive animal production systems and food security. The aquatic production sector can benefit from sharing such knowledge. The starting point of the discussion on sustainable aquaculture designs will be the technical possibilities and limitations of present day aquaculture systems, calling attention to the pitfalls of industrial agriculture development in the last century that should be avoided. A variety of international expertise – within, adjacent to, and outside the aquaculture profession - will be brought together to share experience and insights.

In the following sections we specify the approach to the discussion forum and its organisation. The proposal includes a web-based inventory on "where we stand"; a series of three technical design workshops organised around land-based, coastal and open ocean aquaculture, followed by two design workshops on the regulative and livelihood aspects of these cultures. This series of workshops will be concluded by an international conference dealing with the question:

> **How can aquaculture be designed to be integrated sustainably in the vulnerable aquatic natural world in an ecologically, socially and economically responsible way so that it can live up to its promise of a blue revolution?**

Overall objective

Goal
The goal of the workshops and conference is to formulate a long-term view on the sustainable integration of aquaculture in the vulnerable natural aquatic world, and to provide aid in setting research agendas for aquaculture development.

Strategy
Tackling this goal is by nature a cross-disciplinary and multi-stakeholder task. Where economic, socio-cultural and regulatory aspects are defining the outcome of the competition for space, society requires an ecologically sustainable aquaculture. Sustainability requirements can be envisaged as design requirements for which solutions are to come from a variety of disciplinary and societal viewpoints. The strategy of the workshops and the conference will be to think in terms of design requirements, design strategies and actual designs for aquaculture systems that will meet the criteria of different stakeholder interests: environmental, food security, animal welfare, water conservation, coastal protection, and healthful and safe food. Following this strategy will enable various stakeholders to reconsider their current, somewhat entrenched, positions in the debates on sustainability in aquaculture.

Result
The result of the series of workshops and conference will be:

- A set of design strategies developed from technical, regulatory and livelihood viewpoints for geographically different aquaculture systems that will aid in the formulation of recommendations for research and development agendas, both at the policy level and for the industry.
- A book that summarises the discussions and the outcomes reached through a series of essays and design proposals.
- A policy brief that will summarise the recommendations for a wider audience.

Specific objectives

To reach the overall objective the following steps are to be taken:

Step 1. Secure funding and setup of the organisational framework of the workshops and conference

Month 1 – 3
After securing funding, a Committee of Recommendation will be installed to give weight to the process: prominent members from the sector; research; administrative NGO's and well-known persons will be invited to join. The Committee of Recommendation has the task to lend "name and face" to the workshops and conference. With respect to content and organisation of the five workshops and the conference, a steering committee, consisting of about eight members, will be formed. The members of the committee will be sought among people and organisations that have a global view on aquaculture and sustainability issues in general, that represent different sides of the debate on the sustainability of the aquaculture practiced today and are capable of considering alternative views on its development. As yet the committee has not been established, but the following list is under consideration: Michael New (EAS), (Uwe Barg) FAO, Michael Phillips (NACA), Courtney Hough (FEAP), George Chamberlain (Global Alliance for Aquaculture) and specialists in the fields of the five technical workshops. Also under consideration are opponents in the debate on sustainability, for example, Jason Clay (WWF), Nils Kautsky (Beyer Institute) and Rosamund Naylor (Stanford University); and experts on sustainability issues in general such as, Rudy Rabbinge (WUR), Wouter van Dieren (IMSA), Leo Jansen or Philip Verggragt (DTO; TU Delft) and Pier Velling (IHDP, VU Amsterdam). At least one of the two initiators of the five workshops will hold a seat on the steering committee.

Month 3, 10 and 16
During their first meeting, the steering committee will choose and then invite the initiators of the workshops, set up the conference with regard to content and define the Terms of Reference for both the workshops and the conference. After the series of technical workshops, the committee will (if necessary) adjust the remaining workshops and prepare the conference.

Management and coordination of the internet discussion, workshops and conference, will be done from Wageningen University by the Fish Culture and Fisheries Group (in the remainder of the proposal called "the secretariat").

- Specific objective 1: install a committee of recommendation, a steering committee and organise a meeting to further define Terms of Reference for the workshops, conference and works process of the steering group. Set up the secretariat.

Step 2. Web-based inventory of sustainable aquaculture systems: main problems, potentials and sustainability issues. Development of design requirements.

Month 3 - 8

To embed the process of developing design strategies in reality, the starting point will be an inventory of existing systems that are thought of as "sustainable" or promising developments. The debates on issues of sustainability in aquaculture focus on a number of themes:

- The ecological base of aquaculture
- Ethological aspects of fish-food production
- Food security

Issues related to these or other themes to be further identified by the organising committee can be considered as design criteria for aquaculture production systems. What is the current thinking on sustainable aquaculture designs, i.e. systems and practices? An inventory of sustainable aquaculture designs and a formulation of design criteria will be done by means of a web-based discussion organised by the EAS (European Agricultural Society) and Wageningen University.

- Specific objective 2: To inventory and review sustainable aquaculture designs, both existing and under research.
- Specific objective 3: To formulate design criteria for sustainable aquaculture systems.

Step 3. Workshops for the development of design strategies and designs

Month 1 - 14

A well-designed aquaculture system solves not only technical problems; just as important are management, regulatory, multiple-use and food-security considerations. Efficient use of space will also be a driving force for potential aquaculture designs. To focus the design process, three geographically-based work packages are envisaged:

- Land-based aquaculture systems: from pond to integrated recirculation-system.
- Ocean-based aquaculture systems: from open ocean cage to stock-enhancement.
- Coastal and riparian zone aquaculture systems: from shellfish-culture to artificial up-welling; cultures in multiple use situations.

Each of these work packages will be tackled by a technical workshop led by two aquaculture specialists. During months 2-5, 7-9 and 10-13, the workshop leaders will organise multidisciplinary teams to work out the design strategies. The input to the workshops is the result of the activities listed under Step 2 and a position paper (essay) written by the two specialists for each workshop.

The last two workshops are dedicated to the regulatory and livelihood considerations affecting sustainable aquaculture designs. Whether and how the regulation of aquaculture practices will hamper or constrain new designs can be tested by examining the proposed designs and design strategies from the technical workshops. Equally important is the issue of whether the proposed designs can provide economic subsistence and support for the workers involved: will they contribute positively to the socio-cultural and economic circumstances within a defined ecological environment? Between months 10 and 14, a second set of workshops will examine design proposals focussing on these issues.

- Specific objective 4: To organise three cross-disciplinary workshops focussing on the technical aspects of land-based, ocean-based and coastal aquaculture system design strategies.
- Specific objective 5: To organise two cross-disciplinary workshops on regulatory and economic subsistence considerations of the proposed design strategies.

Step 5. Conference: concluding the design process

Month 18
The goal of the conference is to broaden and deepen the insights of the five design workshops. During the three days of the conference, the first day is reserved for keynote speeches and selected reactions to the workshop results. The remaining days are used for workshops, organised along the lines of the original workshops. Conclusions will be drawn and policy recommendations formulated on the last day of the conference.

- Specific objective 6: To organise a conference: “Sustainability in aquaculture: designing for the future”.

Step 6. Aftercare: dissemination of results

Months 19-24
The last step is to consolidate the results of the workshops and conference by the publication of a book and dissemination of the policy recommendations in a policy abstract.

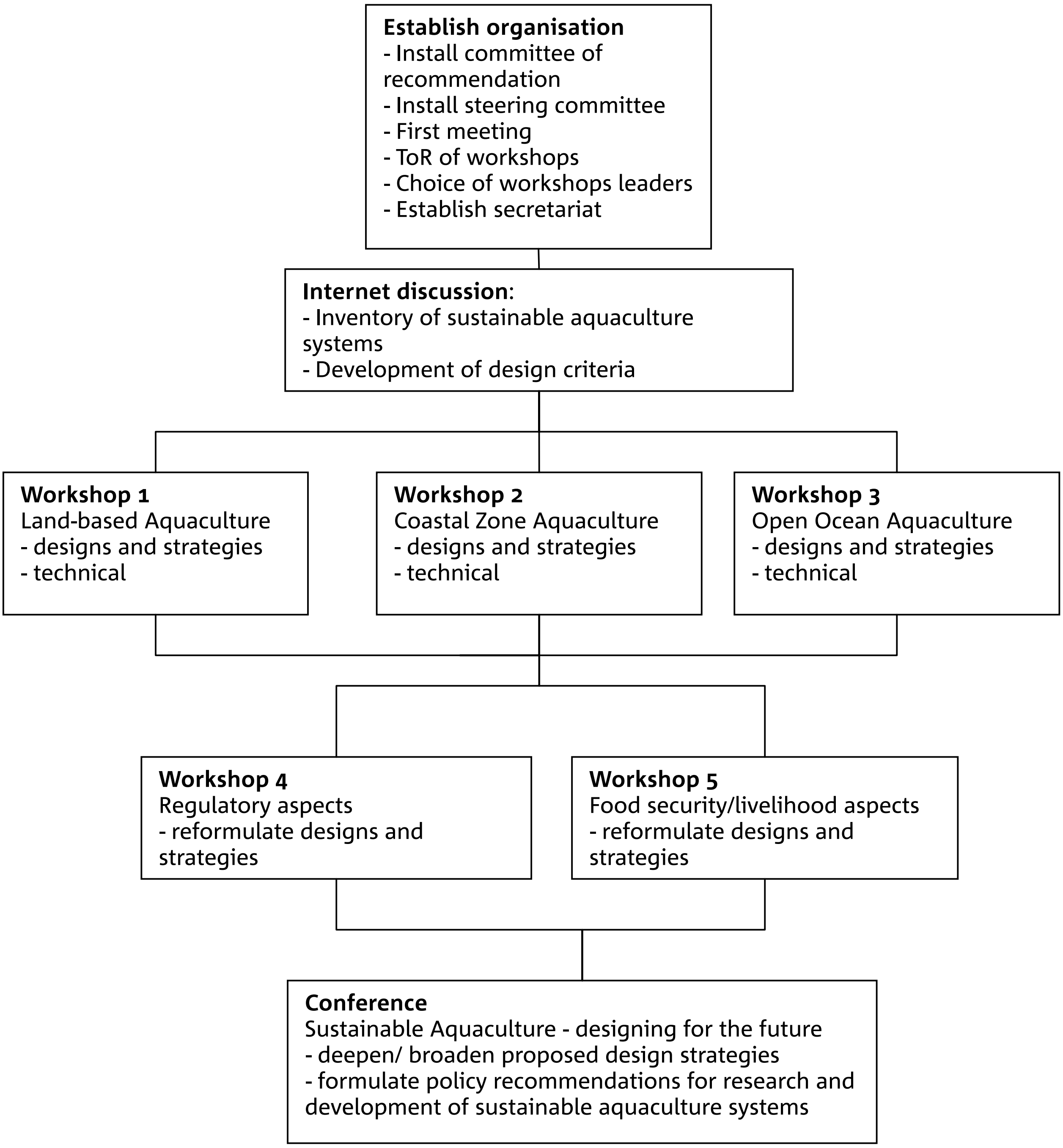

Figure 1. Setup of the discussion platform Sustainable Aquaculture: designing for the future (ToR = Terms of Reference)

Activities – work packages

Work package 1. Setup organisational framework

Months 1 – 3
Aided by the secretariat in Wageningen, the steering committee will:

- Discuss the proposal and prepare the Terms of Reference for its own working process in order to reach the general objective.
- Choose and invite the initiators of the workshops.
- Set the Terms of Reference of the workshops.
- Structure the conference with regard to content.

The first meeting of the committee will be in the first quarter of year 1.

Work package 2. Internet discussion platform

Goal
Assemble an inventory of sustainable aquaculture designs and a characterisation of design criteria.

Organisation: construction (months 1 – 2)
1. Technical construction of the internet discussion site:
   The architecture of the discussion site will be designed by EAS (European Aquiculture Society) in cooperation with the Fish Culture and Fisheries Group, WUR.

The site will include:

- A starting page explaining the purpose of the site.
- A general discussion page.
- A page for announcements on the workshops and the conference.
- A format for three discussion platforms for each of the systems: land-based, coastal-zone and open-ocean.
- A format for two discussion platforms for regulatory and livelihood considerations.

For the technical administration, EAS will be asked to provide personnel.

Organisation: maintenance (month 3 – 8)
2. Content of the site will be maintained by the Fish Culture and Fisheries Group (Wageningen UR), which will organise

- An initiator who will be asked to start the discussion with a statement for the five discussion platforms.
- A discussion leader for each of the five rooms who will ask for reactions and summarise sustainable design criteria.
- Access, which will be regulated by the administrator at the request of the discussion leaders.

Result (month 5 and month 8)
The discussion will be reviewed in a paper on sustainable aquaculture systems (“state of the art”) and design criteria (“future”). Review will be done by the Fish Culture and Fisheries Group in cooperation with the site discussion leaders.

Work packages 3-7: Workshops - general procedures

Goal
Designing sustainable aquaculture systems from technical, regulatory and social-economic perspectives in three geographically-defined aquatic environments.

- All workshops have a two-day duration: a one-day brainstorming session to set design criteria and one day dedicated to designing systems.
- All workshops are introduced through a short discussion paper written by the two invited initiators.
- Additional input to the workshops can result from the internet discussion.
- The initiators can invite other participants (see Terms of Reference - ToR) to individual workshops.
- The outcome of the technical workshops is a set of design strategies and at least one design.
- The outcome of the regulatory workshop is a reaction to the technical designs and design strategies and the formulation of general design requirements for regulatory frameworks.
- The outcome of the food security and livelihood workshop is a reaction to the technical designs and design strategies to formulate general design requirements from this perspective.
- The two group chairs of each of the workshops will work out the discussions in a paper; this will result in at least five papers.
- Other papers are welcome but will not be invited.
- The papers are the starting point for the conference.
- All papers will be published in a book as part of the conference proceedings.
- Terms of Reference for all workshops will be devised by the Steering Committee, but must contain the stipulation that a diverse group of people from within and outside

the aquaculture world will be invited; this will result in a number of designs or design strategies, and a report will be published of the proceedings.

Work package 3: Land-based aquaculture

Goal
Develop design strategies for land-based systems, taking into consideration both intensive recirculation systems and more extensive pond systems.

Potential focus
More than in the other workshops, discussions of intensive (recirculation) systems will focus on animal welfare issues (ethology). Ecological issues are important as well in view of the need to integrate production systems. Food security issues are important in less developed countries.

Participants
- 10-15 people, of whom four to six are aquaculture specialists.
- Proposed disciplines, areas and stakeholders: marketing, sociology, system constructors.
- Initiators: two individuals chosen by the Steering Committee, who will direct participants based on the Terms of Reference the Steering Committee has devised.

Venue
As this topic is related closely to the type of systems researched in Wageningen, we propose to organise this workshop in Wageningen under the auspices of the Fish Culture and Fisheries Group. The workshop will also be a test case for the other workshops.

Time
Months 1 – 5 for preparation, month 6 for the workshop.

Comment
This will be the first workshop to be organised. As such, it will provide a model for the subsequent workshops.

Work package 4: Coastal and riparian aquaculture

Goal
Develop design strategies for coastal and riparian aquaculture systems.

Focus
The starting point for this workshop will be the frontier aquacultures developed in both tropical and temperate systems: the culture of shrimp and salmon. The focus is on integrating aquaculture into vulnerable ecosystems in multiple-function, multiple-use locations. Sustainability issues will be more concerned with ecological impacts and food-security than with issues of animal welfare.

Participants
- 10-15 people, of whom four to six are aquaculture specialists.
- Proposed disciplines, areas and stakeholders: marketing, sociology, system constructors.
- Initiators: two individuals chosen by the Steering Committee, who will direct the participants based on the Terms of Reference the Steering Committee has devised.

Time
Months 7-9 for preparation, month 10 for the workshop

Venue
To be decided.

Work package 5: Open ocean aquaculture

Goal
Develop design strategies for open ocean aquaculture systems.

Focus
Open ocean aquaculture – for instance, ranching, stocking, large cage systems in combination with energy generation – is the least developed both in terms of existing, operating systems and systems in various stages of development. Of the three technical workshops, this will be the most futuristic, with the fewest connections to tried and tested ideas. Sustainability issues are expected to centre mainly on ecological conditions and ecological impacts. But food-security issues could also be important when considering the potential to raise large amounts of cheaply produced fish. For this workshop, animal welfare seems a less important issue.

Participants
- 10-15 people, of whom four to six are aquaculture specialists.
- Proposed disciplines, areas, and stakeholders: marketing, sociology, system constructors.
- Initiators: two individuals chosen by the Steering Committee, who will direct the participants based on the Terms of Reference devised by the Steering Committee.

Time

Months 7-9 for preparation, month 10 for the workshop

Venue

To be decided (one possibility is the EAS conference in Barcelona).

Work package 6: Social/organisational redesign – food security and livelihoods

Goal

To examine and revise the three design strategies developed by the earlier workshops from an employment and subsistence perspective, and based on that analysis, to establish a framework for the design of aquaculture systems from a food-security and worker subsistence perspective.

Focus

Three sets of design strategies have been produced from the three technical workshops. These will be examined on design criteria based on a worker welfare and subsistence perspective. The criteria will be outlined in a paper written by the initiators that will be the starting point of the workshop. Other input will come from the internet discussion. If there is a conflict between the design criteria and the technical designs, both the criteria and the designs should be re-examined.

Participants

- 10-15 people, of whom five are livelihood/social science/economy specialists and five to ten others, three of whom may be the initiators of the technical workshops.
- Initiators: two individuals chosen by the Steering Committee, who will invite the participants based on Terms of Reference devised by the Steering Committee. FAO (Food and Agriculture Association of the United Nations) is particularly interested in this workshop.

Time

Months 10-13 for preparation, month 14 for the workshop

Venue

To be determined.

Comment

FAO is interested in taking part in the organisation of this workshop.

Work package 7: Regulatory redesign

Goal
To examine and redesign the three design strategies from a regulatory perspective and establish a framework for the design of aquaculture systems that takes these issues into account.

Focus
Three sets of design strategies will be produced from the three technical workshops. These will be examined based on design criteria from a regulatory perspective. The criteria will be outlined in a paper written by the initiators that will be the starting point of the workshop. Other input may come from the internet discussion. If there is a conflict between the design criteria and the technical designs, both the criteria and the designs should be re-examined.

Participants
- 10-15 people, of whom five specialists with legal, economic, marketing, administrative backgrounds and 5-10 others, three of whom are initiators of the technical workshops.
- Initiators: two individuals chosen by the Steering Committee, who will invite the participants based on Terms of Reference devised by the Steering Committee. FAO (Food and Agriculture Association of the United Nations) is particularly interested in this workshop.

Time
Months 10-13 for preparation, month 14 for the workshop

Venue
To be determined.

Comment
FAO is interested in taking part in the organisation of this workshop.

Work package 8: Conference Sustainability in Aquaculture: designing for the future

Goal
To discuss design criteria, design strategies and actual designs developed from technical, regulatory and food security/livelihood viewpoints for the three geographically-based aquaculture systems. To formulate research and development recommendations directed at both the policy level and industry.
Setup of the conference

The conference follows the setup of the previous workshops and aims at deepening and broadening the perspectives that arise from the design process. An outline of the conference programme is as follows:

Day one (morning) Keynote speeches with perspectives on
a. Ecologising aquaculture
b. Ethologising aquaculture
c. Food Security
d. Reactions to the designs and design strategies.

Day one (afternoon) and day two:
Workshops that follow the format of the five workshops held earlier.

Day three (morning): Presentations of the workshops, recommendations and plenary discussion.

Day three (afternoon): Plenary adoption of resolutions, concluding remarks and wrap-up.

Participants

At least 100 representatives from a broad range of perspectives including science, industry, administration and advocacy. From previous workshops, at least the initiators of the workshops and the Steering Committee members will be present.

Time

Months 3, 10, 15-17 for preparation; month 18 for the Conference

Venue

Wageningen

Work package 9: Aftercare

Goal

To consolidate the results of the workshops and conference by the publication of a book and dissemination of the policy recommendations in a policy abstract.

Activities

- Edit papers from the internet discussion, workshops and conference, and prepare them for publication.
- Write-up and publication of the policy abstract.
- Dissemination of policy abstract.

Participants

Secretariat in cooperation with the workshop initiators.

Time

Months 19 – 24.

Time schedule

Work package		**Year1**											**Year2**												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Secure funding		X	X	X																					
WP1 Committee				X							X						X								
WP2 Internet Discussion	Development	X	X																						
	Discussion			X	X	X	X	X	X																
WP3 Land-based	Initiation	X																							
	Organisation		X	X	X	X																			
	Execution						X																		
WP4 Coastal zone	Initiation			X																					
	Organisation							X	X	X															
	Execution										X														
WP5 Open ocean	Initiation			X																					
	Organisation							X	X	X															
	Execution										X														
WP6 Livelihood	Initiation			X																					
	Organisation										X	X	X	X											
	Execution														X										
WP7 Regulatory	Initiation			X																					
	Organisation										X	X	X	X											
	Execution														X										
WP8 Conference	Initiation			X							X														
	Organisation										X					X	X	X							
	Execution																		X						
Aftercare	Book/Policy brief																			X	X	X	X	X	X

Budget summary by work package

1. Management and co-ordination (steering committee; secretariat)	€ 47,048
2. Internet discussion	€ 44,800
3. WS Land-based aquaculture	€ 50,013
4. WS Coastal and riparian aquaculture	€ 50,013
5. WS Open Ocean aquaculture	€ 50,013
6. WS Livelihood redesign	€ 50,013
7. WS Regulatory redesign	€ 50,013
8. Conference	€ 158,085
Total proposal	€ 499,998

Financing proposal

Work packages:

1. Steering committee and secretariat:
   financing to be determined
2. Internet discussion, organisation:
   financing to be determined

Workshops

3. Land-based – to be determined
4. Coastal Zone – to be determined
5. Open Ocean –to be determined
6. Livelihood – to be determined
7. Regulatory – to be determined

Conference

8. Conference - to be determined
   It can be expected that the conference will have to be fully funded for those participants who are invited to contribute; other

Book – FRONTIS proposal

To the degree possible, workshops can be held as part of already organised conferences and workshops. NUTRECO has shown interest in having at least one of the workshops held at their Aquavision conference. FAO may be interested in hosting one or two of the socially and regulatory-oriented workshops. The EAS conference in Barcelona will also be proposed as a venue to host one of the technical workshops.

Budget

Work package 1: Management and coordination				
			Costs	Subtotals
			€	€
Preparation and coordination				
	Coordinator		€10,560.00	
	Secretarial support		€4,500.00	
	Office costs		€5,000.00	
Steering committee				
	Travel, lodging, 3 meetings, 6 persons		€25,788.00	
	Rental for meeting facility		€1,200.00	
Subtotal coordination				**€47,048.00**
Work package 2: Internet discussion				
	Development maintenance website		€13,120.00	
	Coordination		€21,120.00	
	Write-up paper		€10,560.00	
Subtotal internet discussion				**€44,800.00**
Work packages 3 - 7: Workshops				
Workshop		**One Workshop**	**All Workshops**	
Meeting centre				
	Rental for meeting facility	€800.00	€4,000.00	
	Badges	€75.00	€375.00	
Scientific programme				
	Travel invited scientists:			
	Outside Europe	€6,000.00	€30,000.00	
	Europe and Israel	€6,000.00	€30,000.00	
	Accommodations invited scientists	€3,150.00	€15,750.00	
Catering				
	Coffee, tea	€840.00	€4,200.00	
	Reception, conference dinner	€2,480.00	€12,400.00	
	Lunch, dinner	€4,960.00	€24,800.00	

Writing invited essays				
	2 persons, 1 month			
		€11,608.00	€58,040.00	
Organisational costs				
	Secretariat	€5,000.00	€25,000.00	
	Coordination	€8,500.00	€42,500.00	
	Office costs	€600.00	€3,000.00	
Subtotal one workshop		**€50,013.00**		
Subtotal all workshops				**€250,065.00**
Work package 8: Conference				
Conference 100 participants				
2 plenary sessions, 2 days workshops				
Conference centre				
include stay in hotel	56-hour arrangement		€21,200.00	
exclude stay	32-hour arrangement		€2,440.00	
	5 small rooms x 1.5 days		€812.50	
	Badges		€500.00	
Scientific programme				
	Travel invited scientists:			
	Outside Europe		€48,000.00	
	Within Europe		€30,000.00	
	Within the Netherlands		€400.00	
Organisation				
	Coordinator		€23,232.00	
	Secretarial support		€11,000.00	
	Office costs		€7,000.00	
Subtotal Conference				**€144,584.50**
Printing costs				
	Book		€10,000.00	
	Policy brief		€2,500.00	
	Distribution		€1,000.00	
Subtotal printing costs				**€13,500.00**
Total budget				**€499,997.50**

Appendix 2: Article Economist

Editoral Economist 368/8336/pg 10.
Article Economist 8-9-2003 - 368/8336/p.19-3 p
Editorial

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Fish farming is a good and promising thing, despite the environmental worries
IF MODERN agriculture were invented today, it probably wouldn't be allowed. It pollutes the environment with pesticides, fertilisers and nutrients from feed and animal waste. Farming damages wild habitats and wildlife. And domesticated animals are stocked at high densities and pumped full of growth hormones and antibiotics, with the result that they are often unhealthily fatty compared with their wild relatives. Now, people say the same sort of things about aquaculture. But it would be a calamity if rows about the environmental effects of fish farming prevented the development of a new industry, with the potential to supply most of the world's fish.

All farming alters, and sometimes damages, the environment. Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism and home-owners as well as environmentalists for access to the coast. Agriculture had the luxury of being able to pollute and alter the landscape first and worry about the consequences later. Not so aquaculture. Nevertheless, there is no sense in expecting modern aquaculture to emerge immediately as a perfect food supply that pleases everyone from animal lovers and greens to economists and industrialists. The challenge will be to regulate it prudently and efficiently, not just in the rich world but in poor countries and eventually farther out to sea, too.

The devil and the deep blue sea
Certainly, plenty of fish farming makes a nasty mess. Shrimp and salmon aquaculture, which have shown astounding double-digit growth in the past decade, present particularly worrying environmental challenges. But the salmon was first domesticated in the 1970s. Early industrialists made a nasty mess too. However, whereas it took a century to begin to clean up the filth of the Industrial Revolution, improvements in technology are already cleaning up fish farming, at least where the industry is well regulated ()see pages 19-21. For example, the release of waste nitrogen from farming salmon in Norway is now one-sixth of its level 30 years ago; and the amount of feed required is less than half. Indeed, organic farmed salmon is now available to consumers who are worried about marine pollution and antibiotics. Such progress is all the more remarkable given how quickly it has been achieved.

In less developed countries, it is true that much of the industry is poorly regulated. But even here, environmental concerns about fish farming need to be put in context. For example, in less developed countries, such as Thailand and Vietnam, it is well known that shrimp aquaculture is exceptionally destructive to mangrove forests, which are essential for healthy populations of many wild fish. What is less well advertised is that, whereas 55-60% of mangroves have been lost globally, conversions to shrimp farms probably account for less than 10% of this loss. The rest is down to factors such as rice production, grazing, urban development, fuel, construction materials and tourism--all of which inspire less outrage. And shrimp aquaculture, if undertaken responsibly, is arguably a better use of the land than these other options. It is a compact and efficient way of producing a highly nutritious form of food, and an important way to alleviate poverty.

There are, though, some serious questions to be asked about certain sectors of fish farming. One of the world's most respected fisheries biologists, Daniel Pauly at the University of British Columbia, argues, naturally enough that there are good and bad forms of aquaculture. The good forms include plant-eating fish such as tilapia--popular in America--and filter-feeding creatures such as scallops, mussels and oysters. Tilapia, he argues, could become the chicken of the sea and produce a net increase in the world's supply of fish. Salmon and sea bass, he argues, are the bad guys, fed on wild fish caught in the ocean. If this kind of farming, widespread in the developed world, becomes popular elsewhere, it may aggravate, not diminish, pressure on the marine environment and on the world's supply of fish. For the moment, however, farming of the good guys represents 80% of global aquaculture.

In cod we trust

In the rich world, the industry urgently needs a certification scheme for farmed fish. Even carnivorous fish can be fed sustainably, by feeding them on fish that has been caught from a renewable (and not a plundered) fishery. Such a certification scheme is already being developed for wild fisheries.

International regulation may also be necessary to address a problem that technology is likely to throw up in the next decade. It will become increasingly possible to farm fish on the high seas, something known as mariculture. At the moment, one of the benefits of aquaculture over oceanic fisheries is that it occurs within the boundaries, and regulation, of governments. If fish farming starts to become a big business in international waters, it could become a big, hard-to-regulate and polluting industry: in other words, a tragedy of the commons. Before that happens, and before large investments are made and governments feel obliged to start defending national interests, mariculture needs common international standards.

Up to now, the world has been dreadful at regulating fishing. The catching of wild fish has long since passed the point at which most fish stocks are sustainable. Catches are declining, and that decline may gather speed. If governments are willing to end the subsidies that keep ocean fisheries afloat, then unsubsidised fish farming could replace at least part of the lost catch. Besides, if governments do not stop subsidising sea fisheries, then the lower costs and greater scope for technological advance in fish farming will make sea fishing less and less competitive, and relentlessly drive up the cost to the public purse of supporting an uneconomic business.

Aquaculture's promise is that, within the next three decades, it could produce most of the world's marine produce. At the same time it could help to alleviate poverty and food shortages in some of the world's poorest countries. And if it is done well, it could help to safeguard marine resources for future generations. That, surely, is something to nurture.

Article

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Abstract: This article describes the possible benefits of fish farming as an answer to a global demand for fish. Its supporters argue that it promises to meet the growing shortfall as the world's wild fisheries become more and more exhausted. Critics portray fish farming as an alarming environmental and health hazard, not a potential source of food for the world's rich and poor alike. But they glide quickly over the fact that modern aquaculture is at an early stage of development. Many now believe that the global catch has actually been in decline since the mid-1980s. This should come as no surprise: some 75% of global fish stocks are depleted in some way. The reason that people have been able to continue to eat more fish in spite of the over-exploitation of wild fisheries is because aquaculture production has been booming. Mirroring developments in the green revolution, the blue revolution has seen companies breeding fish to improve traits such as their growth rate, conversion of feed into flesh, resistance to disease, tolerance of cold and poor water, and fertility. There is already much talk of using genetic modification (GM) in fish farming. Aquaculture has brought two crucial changes to the seafood industry: consistency of supply and lower prices.

Fish farming - The promise of a blue revolution

How aquaculture might meet most of the world's demand for fish without ruining the environment

Fish farming has a bad reputation. Its supporters argue that it promises to meet the growing shortfall as the world's wild fisheries become more and more exhausted. But its critics have the louder voice. They argue that farmed fish is fatty, dyed, polluting and stuffed with antibiotics. Moreover, they say that it is unsustainable. When a carnivorous fish--such as the salmon--is reared on a farm, it too must be fed with fish. And these fish must be caught in the wild, thus putting even more pressure on marine life, not less.

The critics portray fish farming as an alarming environmental and health hazard, not a potential source of food for the world's rich and poor alike. But they glide quickly over the fact that modern aquaculture is at an early stage of development. Commercial agriculture has developed over centuries; large-scale commercial aquaculture is little more than 30 years old. New technologies, new breeds and newly domesticated species of fish offer great hope for the future. They promise a blue revolution in this century to match the green revolution of the last.

On land, human beings may be committed agriculturists, but in the sea they remain largely hunter-gatherers--albeit hunter-gatherers with industrialised fleets equipped with satellite and radar. In 2000, the world landed 95m tonnes of wild fish, with a first-sale value of $81 billion, according to the Food and Agriculture Organisation (FAO). Although this appears to be the highest catch of fish ever recorded, the figure is almost certainly wrong.

In the past year, it has become clear that statistics from China, the world's largest supplier of fish, have been inaccurate for at least a decade. Many now believe that the global catch has actually been in decline since the mid-1980s. This should come as no surprise: some 75% of global fish stocks are depleted in some way.

As people get richer, they eat more fish. Average consumption per person has almost doubled in less than half a century. And fish has certainly become more expensive as demand has increased and supply declined. There are still not enough farmed fish to stem this price rise. Some products, such as wild salmon and blue-fin tuna, are now luxuries. Nikolas Wada, a researcher with the International Food Policy Research Institute, says that the rise in seafood prices is even more remarkable when set in the context of prices for other animal products--such as beef, chicken, pork and milk--which have plummeted in real terms over the past 30 years.

The reason that people have been able to continue to eat more fish in spite of the over-exploitation of wild fisheries is because aquaculture production has been booming. In 2000, the industry produced 36m tonnes of fish and shellfish. Since 1990 the industry has been growing at an average compound rate of around 10% a year. It is probably the world's fastest growing form of food production. (By comparison, farmed meat production grew by 2.8 %.) Already, around half of the fresh and frozen seafood consumed by Americans is farmed. Some people believe that, by 2030, aquaculture will supply most of the fish people eat.

The problem with some of these global figures is that nobody is sure how inaccurate China's statistics are. The country is without a doubt the world's largest producer of farmed fish and has seen strong growth in recent years. Official figures put its contribution at over 70% of the world's farmed fish and aquatic plants. But if China's production figures are out by only a little, many global predictions are out by a lot. Without China's contribution, aquaculture's growth since 1990 would have been less than 5% per year.

Nevertheless, there is still plenty of cause for optimism. On land, the green revolution allowed dramatic increases in crop production, with increased mechanisation, and improved pest control and soil fertility through the addition of herbicides, pesticides and nitrogen-based fertilisers. In the water, similar kinds of things are happening too. The stage is being set for an aquacultural revolution.

Blue is the colour

Traditional aquaculture, of the kind that the Chinese invented many thousands of years ago, is a low-tech affair involving no more than a pond, some rotting vegetables and a few freshwater fish that are not too fussy about the quality of water they live in or the proximity of their neighbours. There is still plenty of it about. Jiansan Jia, an aquaculture expert at the FAO, says that 80% of the fish produced by aquaculture are herbivorous or omnivorous, mostly produced in low-intensity systems for local consumption. Such fish do a great deal to alleviate nutritional deficiencies and poverty in rural areas, and may yet become a big contributor to local food supplies in most developing countries.

However modern aquaculture, the kind that began with salmon about three decades ago, is a different matter. It involves technically specialised conditions and a great deal of knowledge about the habits and life cycle of each fish species.

It can take years of research to domesticate a new species. Stocking densities, water quality, breeding conditions, animal behaviour, health and precise nutritional requirements have all to be worked out in detail to domesticate wild fish such as the salmon, sea bass, flounder, halibut, sole, hake, haddock and sea bream. And it is scientific and technical knowledge that is driving competitiveness in the industry, by improving fish health and nutrition, and by reducing stress, disease and the use of antibiotics and vaccines.

Mirroring developments in the green revolution, the blue revolution has seen companies breeding fish to improve traits such as their growth rate, conversion of feed into flesh, resistance to disease, tolerance of cold and poor water, and fertility. Breeding tilapia (a freshwater, plant-eating fish popular in America) has produced a strain that is hardier and grows 60% faster than the wild variety.

This is only the beginning. There is already much talk of using genetic modification (GM) in fish farming. Scientists are tinkering with a salmon that carries a gene inducing the production of a growth hormone, which make the fish grow bigger and faster. This project, though, is even more controversial than farming GM crops because of concerns about what might happen if fish escape. No GM fish are being farmed for food at present.

Aquaculture has brought two crucial changes to the seafood industry: consistency of supply and lower prices. Dennis Overton, the managing director of Aquascot, a fish-farming operation in the Scottish Highlands, says that aquaculture has led to an increase in demand for fish. Before salmon were farmed, supermarkets found the unpredictable supply made it difficult to sell. Now salmon can be sold in the same way as beef or lamb, and this, he says, has had a huge impact on sales.

The market is growing fastest in North America--by 12-13% a year in recent years. Salmon is now the third most popular seafood in America. A decade ago, Costco, a big retailer, did not even stock fresh fish. Now it sells 15,000 tonnes of farmed salmon fillets a year. The same story applies to shrimp, now America's most popular seafood.

Scottish Quality Salmon, which represents the salmon-farming industry in Britain, says that in the early 1980s farmers received £11 a kilo ($10 a pound), but increased production and Norwegian dumping drove this down to £3 a kilo in the early 1990s. In 2002, the equivalent price was £1.90. Not all these improvements have been passed on to consumers, however. The retail price of salmon has not changed in Britain in the past decade.

For the future, says Richard Slaski of the Federation of Scottish Aquaculture Producers, it is halibut and cod that are causing a "huge wave of interest in northern and western Europe". Cod is (literally) the great white hope of European producers who are facing tough competition from cheap salmon production in Chile. Intensive research efforts are under way in France, Norway and Scotland to farm cod with complete predictability. It is a difficult business. Unlike salmon, cod fry do not have large yolks that they can live off in the early days of their lives. They must be fed, and fed correctly, almost as soon as they have been hatched.

Mr Overton says that Aquascot will breed cod to order from customers, rather than breeding lots of it in the hope of finding a market. But not everyone is thinking this way. "Our colleagues in Norway say they are going to produce thousands of tonnes," says Mr Slaski, although "they have not addressed the issue of where they are going to sell it." However, given that catches of wild cod have dropped by two-thirds in the past three decades, there is a clear gap in the market.

Cleaning up
It is pollution not revolution that most folk associate with aquaculture. And indeed, broadly speaking, modern intensive fish farming does harm the environment, although the extent varies enormously. But so does agriculture, and that has not detracted much from beef sales. The issue, of course, is whether society is willing to pay the price.

Waste from fish farms--such as uneaten food and dead fish--can accumulate and destroy parts of the sea. The overuse of antibiotics can threaten both marine and human health. And fish may transmit diseases such as sea lice to wild stock, or breed with wild fish causing "genetic pollution". In the past decade, 1m non-native Atlantic salmon have escaped from fish farms and established themselves in streams in the north west of America. There are some fjords in Norway where 90% of the fish have escaped from farms.

Shrimp aquaculture also causes serious environmental problems--especially in countries with poor environmental regulations. These problems include the destruction of wetlands and mangroves, the dispersion of chemicals and nutrients, and the salinisation of the soil. A recent study by the Environmental Justice Foundation says that, in the Cau Mau province of Vietnam, the world's fifth-largest producer of farmed shrimp, the Mekong Delta's mangrove cover is 30% of what it was in 1975. Shrimp aquaculture is easily the main cause. Elsewhere, though, aquaculture has probably contributed to the loss of less than 10% of the world's mangroves: the rest is due to causes such as rice production, grazing, urban development and tourism.

The good news is that well-regulated countries have done something about the industry's poor environmental performance. One result has been feed formulations that are more digestible and that leach less waste into the environment. The EWOS group, one of the largest feed suppliers to the salmon-farming industry, is spending more than euro10m ($16m) a year on improving nutrition, feed development and fish health. Kjell Bjordal, its chief executive, says that one measure of the release of waste--the nitrogen loading of the water--has declined sharply. In 1972, it was 180kg per 1,000kg of Norwegian salmon produced; today, new feeding technologies have brought it down to 30kg. The amount of feed used for growing salmon is 44% of what it was in 1972.

Mr Slaski says that the use of antibiotics in Norwegian aquaculture is less than 0.5% of what it was ten years ago. Vaccines have brought about great reductions in the use of antibiotics and other chemicals. Even shrimp farming need not be an environmental nightmare, agrees Jason Clay, an aquaculture expert at the World Wildlife Fund in Washington, DC. And in Florida, Ocean Boy Farms claims to be able to produce a marine shrimp that does not pollute the environment. Their inland shrimp farm uses another fish, the tilapia, to mop up the shrimps' waste. A similar technique is being tried by a farm at Mikhmoret, Israel. Such land-based, integrated farming techniques offer great promise but with minimal environmental cost.

Making a meal of it

Aquaculture's critics say that, despite all this effort, the industry has a fatal weakness. The problem was outlined several years ago by scientists who calculated that several kilos of wild caught fish were needed to feed every kilo of farmed salmon or other carnivorous fish such as eel or striped bass. This, it is argued, means that modern aquaculture is increasing, not reducing, the pressure on marine animals. Dan Barlow, of Friends of the Earth in Scotland, says it is even wors for cod. The sand eels that are caught in the North Sea for the farmed cod are supporting the marine food chain there. "You are robbing Peter to pay Paul," he says, and wild cod will never recover.

Yet despite the growing popularity of farmed carnivorous fish, there has been no corresponding boom in catches of the food they eat. The world's catch of "industrial" fish--mostly anchovies, sardines and menhaden--that is used to make fishmeal has remained resolutely stable at 30m tonnes for decades. The reason for this mystery is that in the past fishmeal was used to feed animals such as poultry and pigs, but this has been cut back. Many argue that using fishmeal to feed fish is, in fact, more efficient than using it to feed terrestrial animals. Today, fish farms use about 40% of the world's supply of fish oil, and 31% of its fishmeal. Many, including the FAO, predict a worldwide shortage of fish oil within the decade.

Technology may help to avert it. Mr Bjordal says the fishmeal content of fish feed has been reduced from 70% in 1972 to 35% today. He believes his firm can cut the use of marine resources in half again without reducing the amounts of key fish oil--omega-3--which is the main reason why fish is seen as a healthy food. Replacement feedstuffs such as soya, rapeseed oil and corn gluten are being developed. Chinese researchers are working on a yeast-based protein supplement that could be a substitute for more than half the fishmeal.

How fast this resource runs out depends a great deal on what China does. It is now the world's largest importer of fishmeal and, if that continues, the FAO dryly observes, it will have "a serious impact on the rate with which the requirements for marine resources may potentially equal supply."

The most serious concern if fishmeal were to run out, argues Mr Wada, would be the diversion of low-value fish from the mouths of people in developing countries into the mouths of well-fed fish in the developed world. However, if the price of fishmeal rises, a way might be found to harvest unexploited stocks of hard-to-catch industrial species such as krill. This would, though, reduce the amount of food available for large fish and marine animals. Alternatively, more use could be made of what is known as "bycatch". This is marine collateral damage: the fish that are accidentally caught, killed and then thrown back in the water when other fish are the target. Bycatch amounts to tens of millions of tonnes of fish every year.

Aquaculture has one important advantage over open access fisheries: it can be more easily governed. Environmental pressure can, and does, force the industry to change. The same cannot be said of the open seas, where nations compete furiously for a dwindling supply of wild fish, and politicians routinely ignore scientific advice. While fishermen can work only on improving the efficiency with which they capture the few remaining fish, aquaculture can work at lowering its costs of production and increasing its profits. As it does so, it may start to undercut the costs of open-seas fishing to the point where the government subsidies given to ocean fisheries become patently ridiculous. In this way, farming might one day relieve the pressure on wild fisheries.

Certify them
If the past history of agriculture is any guide, aquaculture will surely find a way to meet the world's demand for fish. The big question is: will this be done in a way that pollutes the marine environment unacceptably? As consumers become more aware of the sources and the means of production, they may insist that intensive, modern aquaculture should grow in environmentally sustainable ways.

The problem is that good independent information about the environmental friendliness of farmed fish is sorely lacking. Standards vary widely among countries, and raising standards in one place may drive the industry (and its pollution) somewhere else with weaker rules. An internationally recognised certification scheme, along the lines of dolphin-friendly tuna, is urgently needed to alert consumers to the sustainability (or otherwise) of the farmed fish that they are eating. Only in this way can consumers hope to find out whether the products of modern aquaculture are doing more harm than they prevent. And only then will it be clear how green is the blue revolution.

Appendix 3: First e-mail, the appetizer

(Sent between 11 September 2003 and 11 October 2003)

L.S.,

"Quidquid agis, prudenter agas et respice finem"
(whatever you do, do it prudently and think as far ahead as possible)

Aquaculture is at a crossroads, and has some large hurdles to take to come of age in the twenty-first century. This is the tenor of the article published in the Economist of 9 August 2003. The editorial preceding the article puts it like this: "*Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism and home-owners as well as environmentalists for access to the coast. Agriculture had the luxury of being able to pollute and alter the landscape first and worry about the consequences later. Not so aquaculture.Nevertheless, there is no sense in expecting modern aquaculture to emerge immediately as a perfect food supply that pleases everyone from animal lovers and greens to economists and industrialists. The challenge will be to regulate it prudently and efficiently, not just in the rich world but in poor countries and eventually farther out to sea, too*". Sustainability issues rank high from whichever angle the development of aquaculture is approached. For aquaculture to be the answer to the global demand for fish, in a healthy diet for the rich and to feed the poor, it has to conform to present day ecological, societal and economic demands: the blue revolution needs to be green as well and many colors besides. But, regulating may not be enough. The rate of increase in global aquaculture production is slowing in many parts of the world. Perhaps this is due to production limitations, in which case current technologies may not suffice or be used very well. Fundamental innovations in aquaculture technology then would be needed. But, there could be other, societal, limitations as well.

The Fish Culture and Fisheries group of the Wageningen University Research together with Innovation Network Rural Areas and Agricultural Systems is organising a series of workshops to develop scenarios of aquaculture development culminating in an international conference dealing with the question

- How can aquaculture be sustainably integrated in the vulnerable aquatic natural world in an ecological, social and economic responsible way and live up to its promise of a blue revolution?

We would like to ask you to take part in this. In this letter we will outline the background, the goals, intended process and outcome of the workshops, some possible starting points for discussion, and end with some questions regarding the role you may wish to play.

The Netherlands and in particular Wageningen University obtained quite some experience with discussions both around intensive animal production systems and issues of food security, and with that has something to offer to the aquatic production sector. On the other hand, this Dutch experience does not extend into aquatic environments. The debate on sustainability of aquaculture is part of the international concern for "Ocean Governance". Therefore it is necessary to bring together a variety of international expertise to learn from each other's insights. Central in the workshops and the conference will be scenarios for aquaculture development that will meet criteria of different stakeholder interests: environmental, animal welfare, water conservation, healthy and safe food, food security .... The outcome of the conference will be an evaluation of different scenarios for aquaculture development in the next 25 years, painting different futures, and pointing new directions for innovative research and development. Which future(s) would today be the most accepted? Which are the most realistic? What is technically, socially and economically needed to reach desirable outcomes?

During the first workshop preceding the conference a mix of experts from different fields relating to aquaculture - with diverse, irreverent, viewpoints on its future – will devise the scenarios in a brainstorming session. The possible futures of aquaculture will be constructed in as much detail as possible in between and during a subsequent workshop. During the final conference the scenarios will be presented and discussed in workshops by different stakeholders, weighing assumptions, values, pros and cons from different angles to sustainability. The goal will be to challenge common assumptions behind current thinking on aquaculture development, to try to understand critical uncertainties and to arrive at inclusive and realistic requirements for desirable developments, both in the rich and poor parts of the world.

The starting point is the technical possibilities and limitations of present day aquaculture while avoiding the pitfalls of industrial agriculture development of the previous century. Some themes - or dichotomies - could be:

Culinary diversity....
the general consensus among aquaculture specialists seems to be that species diversification is not a research priority - especially not of carnivorous species. To exaggerate: forget about the beautiful diversity of sea-products now coming from fisheries and lets all eat salmon, oyster and shrimp (and all the varieties that the future will give us on these animals ...and don't forget tilapia and carp). However, the world apparently takes another course: the number of cultured species now is up to 262 according to some sources and is in different parts of the world – including Europe and North America - now between 2 and 10 times higher than in the 1970's.

....leading to multiple functions of aquaculture.
Species diversification may not be a research priority from the point of view of developing intensive cultures; it could be a priority for other purposes: conservation of endagered biodiversity (zoos, biodiversty parks); redirecting people from fisheries on lucrative species in vulnarable coastal ecosystems (groupers, plaice etc.); food security. The main function for aquaculture will remain food-production but its importance in various other services - nature conservation, recreation, water management, food security - and with that the need for diversification could increase. Can these divergent goals meet? Would this be desirable? What kind of knowledge would there be needed?

Ecologising aquaculture
Diversity also plays a role with thoughts of integration of systems into agriculture, or of using plants and animals to control flows of nutrients both in intensive and extensive, closed and open cultures. But here we also may think about impacts of aquaculture on natural ecosystems as became clear in the intensive (resolved?) debate on the use of fishmeal for fish feeds - a diversion of food from natural and a redistribution within human food chains. But what about the solutions: for instance using vegetable feeds – another redistribution from one human food chain to another? Or harvesting nature again to feed fish but now lower in the food chain (calanoid copepods; krill; mussels). But why not try to use primary consumers (shellfish, sea urchins, cucumbers, bagpipes) more directly for human consumption through approaches to increase the value of low-in-the-foodchain products – Pauly's "fishing down the food web" may then be a goal – "culturing down the food web" - and not a

threat. Lastly, sea ranching and stock-enhancement technologies combined with intensifying ecological processes as with *in situ* artificial upwelling may lead to thinking about sea-pastures. The possibilities seem almost limitless once one starts to think about the technical potential of combining knowledge of ecological processes with aquaculture production systems. But what is feasible? What is desirable? How will it solve issues of sustainability?

Ethologising aquaculture
A true aquaculturist tries to control all stages in a life cycle of a fish through prodding its physiology and controlling its feeding within a more (preferably) or less closed environment. The large aquacultures in Europe and North-America, following classical animal-breeding scenarios, have been quite succesful with this approach and some are very promising: life cycles are then, it is said, almost closed. It is one of the main reasons for claiming that diversification is not a research priority: it will simply cost too much to do this for all these potentially useful species. But what about fish behaviour: groupers could be made to spawn in captivity in open-water cages by using careful observations of spawning behaviour of males and females in the wild. Perhaps a less closed life-cycle but more animal-friendly and again potentially solving some of the wider sustainability issues mentioned earlier: redirecting poor people from lucrative fishing in vulnerable coastal ecosystems.

Food security
Many issues here, but let us take Africa: often considered a sleeping giant when it comes to aquaculture potential, but past failures in introducing aquaculture in this continent even have lead to, at least temporarily, a reduction in donor assistance to this technology that promised so much. Attention to livelihood systems now may give a new impetus. Yet, again, here it may be that the technologies themselves offered, mostly depending on single species and the need to efficiently use land, labour and other inputs may not fit African rural experiences where food production often depends on high labour input in mixed, extensive, systems in highly variable environments. Thinking about technologies that can fit in with such experiences may even lead to a convergence when adressing the popular wish in in particular European countries for more 'natural' production systems. It also may even require more technology – biotechnology, information techology - instead of less. But there is also a need and a drive to produce a lot of food that is relatively cheap ……

There could be other avenues to follow. For instance, how can scarce water resources be utilsed more effectively? Spatial incorporation of aquaculture in fresh and marine coastal zones without habitat destruction and maintaining other functions of these areas require different ways of thinking about aquaculture, as is abundanly clear from the experiences in shrimp cultures in SE Asia. What can aquaculture contribute to integrating production systems in coastal areas?

For now I would like to ask you:
- Would you be interested to take part in the development of the workshops preceding June 2004, to help sharpen their goal and intended outcome in relation to current debates on aquaculture? The start of this process is now, with this letter, and your answer. Based on your and other invited reactions we will set up a discussion platform – either through e-mail, or through a website, in which these directions will be explored and be used as a starting point for the workshops.
- Would you be interested to take part in the initial scenario design, the scenario development and/or the final discussion on scenarios? The starting workshop would be in June 2004 a second workshop around September 2004 and a final conference around November 2004?
- Could you advise on persons (globally) who according to you could be particularly useful to take part in the proposed initial discussions and in the process of scenario development?

I will be very pleased to hear from you,

With kind regards,

P.A.M van Zwieten

Appendix 4: Second e-mail, towards designs

(sent between 8 October 2003 and 20 October 2003)

L.S.,

Thank you very much for your positive reply on our “appetizer” for the workshops and conference on sustainability in aquaculture. This reaction has taken some time, but we preferred to await the reaction of others to judge whether it was useful to continue. It is: many have responded positively on this initiative!

In the following I will present some further ideas on goal, approach and process of the workshops on which I would like to have your reaction and advise. We are still developing it. Then I would like to ask you about promising developments in aquaculture and aquatic production systems. Lastly I will react to some issues on some practical matters that you or some of your colleagues raised.

One of the goals of the **preparation** of the workshops is to start-up a discussion on the directions to take for innovative research and development in world-aquaculture. Your input to this will be highly valuable. Talking about “world-aquaculture” may easily lead to high-minded statements that do well in a political arena, but that is not what we are after here: the intention of the workshop is to help envisage solutions to (broadly stated) sustainability problems and potentials around aquatic food production over a long time frame. One of the reactions was to the propositions to the first mail was: “ very interesting ideas, concepts and suggestions – which if debated and thrown around, may just shed some light in the path of a currently somewhat blinded giant”. This is what we are after.

Goal, approach

Taking the long-view on sustainable integration of aquaculture in the vulnerable aquatic natural world is the proposal for the workshops. In our mail we proposed to do this through the development of scenarios, through which we can question our broadest assumptions, and develop strategic directions for innovative research and development to reach stated values of sustainability. But we may have to take it further: scenario building is a good tool to order one’s perceptions on alternative future environments in which today’s decisions are being played out – evaluate technical and socio-economic constraints that will steer developments, or conversely how to reach certain goals given technical and social/economic conditions. But, as I stated in the previous mail: current technologies may not suffice or be used very well, in which case fundamental innovations in aquaculture technologies would be needed. Therefore I would propose to think more in terms of innovations to reach sustainability goals given the need for increased food production from aquatic environments. To keep the discussion in as practical terms as is possible, the strategy then would be to think in terms of designs and design strategies for future aquaculture systems or - more broadly - aquatic production systems. The goal of the series of workshops will be to develop a number of designs and set out design strategies – for instance three or four - for aquaculture systems (system in a broad sense, as in ecosystem). The result of the workshops will be a series of research and development recommendations to be taken up at policy level – next to a book with worked out essays, proposing innovative solutions to sustainability issues in aquatic production.

1. Scenario

An approach like this could start from a very general scenario: more than 70% of the earth is water. Only 10% presently is useful for agricultural production. That is: it was 20% before humans really started to intervene. Given present agriculture practices it could be expected that within a century only 5% of the earths surface will remain intact for agrarian use. With a still increasing world population and increasing food demand structural problems will arise and new sources of food production will have to be found. The demand for utilising coastal and marine environments more efficient than we do now – many seas are over fished, but marine biomass is underutilised[9] - and systems to realise that, will increase. But, his production not only needs to be realised just one way or another, it also must be realised taking into account sustainability issues as the long term production potential and carrying capacity of ecosystems on which aquatic production systems would depend; food security including issues of entitlements; issues of multiple spatial demands in coastal and riparian zones; issues of work and money; perhaps even aesthetic issues - certainly playing a role coastal planning. This means that the effectively or efficiency demands with which aquatic products are to be produced are even higher than based on simple extrapolation of demands of increasing population.

2. Design requirements
Three focus areas were described in the first mail covering the main problems and potentials for aquaculture. They were titled “ecologising aquaculture” , “ ethologising aquaculture” and “food security” . Issues of diversity and addressing multiple-functions of aquaculture can be subsumed under these three. In a design mode these focus areas will be explored further: the issues mentioned under these headings can be seen as values, principles or ….. design requirements. In no particular order of importance and with, as yet, no precise definition some of these were: diversity in cultured species; integration of production systems; utilising lower trophic levels for feed or food production; animal-friendly techniques; considering (human) cultural practices; recycling of nutrients; incorporation of aquaculture in coastal zones (“scenic aquaculture seascapes”); functions in conserving biodiversity and resource base; food security framed in livelihood systems; “natural” production systems etc. etc. *In the preparation of the workshops a major task will be to clarify these design requirements. We would like to ask you to react on this. What other requirements would you propose? What is your understanding of the ones mentioned?*

3. Designs and design strategies
Browsing through the EAS special publication “Beyond Monoculture” – the themes discussed at this conference seem to extend naturally into our workshops - it becomes clear that “sustainable integrated aquaculture” is viewed mostly from the perspective of nutrient, particle and/or water flows generated by the cultures practiced. Integration is then seen as utilising these flows by coupling separate compartments, e.g. coupling recirculation systems with hydroponics, or using different flows within a system, as in pond polycultures, or as co-cultivation in open systems, e.g. rearing Laminaria and blue mussel next to Salmon cages. Integration is rarely seen as in conjunction or as combined with solutions for sustainability issues in other spheres than from the perspective of aquatic food production, e.g. energy, coastal defence, livelihoods etc. This is not to criticise this conference of specialists with their professional concerns, but it could be symptomatic for the field. Ideas rarely meet: often solutions to sustainability problems from other spheres utilising aquatic properties, contain the statement “…. and you can also raise fish in it ….” to which the aquaculturist either forgivingly reacts “ don’t you know how difficult it is to raise a fish” or angrily “but that is not aquaculture…” . If issues of access to coastal and near shore aquatic resources for aquaculture or of incorporation of it to reach sustainable livelihoods are

[9] Or: as a paper in Fish and Fisheries (Cury and Cayre, 2001, 2:162-169) would have it: Hunting became a secondary activity 2000 years ago: marine fishing did the same in 2021

to be tackled this type of integrated designs have to be thought through cross-disciplinary. Doing this will be the task for the workshop and the conference.

The approach has a deliberate technological focus: though issues of sustainability are to be approached in terms of people, planet and profit, in the end fish and seafood needs to be produced in or outside fish tanks at a certain spot by people that take care of them and/or harvest them. Innovations in aquaculture are needed: the salmon model based on the models of intensive livestock farming, needs to be rethought in terms of integrated designs while the shrimp model, is based on an old-fashioned frontier mode of unrestrained re-designing of coastal zones as in earlier agricultural practices of opening up “wastelands” and other “Wuthering heights” for food production. Both modes of utilising aquatic resources now have a rather bad press, at least in richer and more northern climates, and more integrated, sustainable designs are needed.

One approach we do not wish to pursue is the regulatory path: presently the focus, also referred to in the article in the Economist of 9-8-2003, is on regulating the industry. Notwithstanding the present need to do so, the question may be raised if and how regulating, certification, soft and tough approaches, codes of conducts etc. in aquaculture practices may lead to the necessary innovation. However, present experiences with existing aquaculture systems no doubt will inform what is necessary and feasible, even in the long-term. But also: examples of where regulation has lead to technological innovation could be useful for our discussion as well.

Your comments on the goals and approach taken at this stage is absolutely necessary. Will the proposed approach lead to a fruitful exchange of ideas? What are the pitfalls and how can we avoid them? Is the general scenario described a sufficient starting point? What design requirements are to be added, dropped? And lastly:

A request for examples
To make the discussion concrete we would like to have a collection of examples of designs – green and worked out – that can assist in reviewing the status of thinking on integration of aquaculture. **What according to you are good or promising examples of aquaculture systems, designs and practices?** These may be existing practices, research designs or paper designs. They may be more or less integrated. Why is this a good design? What design requirements are fulfilled, or, if you will what sustainability issues does it solve? References to literature or internet sites are welcome as well.

Process
Your reactions will be compiled and reviewed in a report - of which you will receive a copy – and that will form the basis for the workshop. Further preparation to the workshop a website discussion platform will be opened as a place for debate and reflection, to generate ideas and collect different viewpoints on the design. The site will launched three to four months before the start of the first workshop. However, there may be a need to start the discussion earlier: in that case we have been gracefully offered to make use of the AQUACULTURE-IMPACTS mailing list http://lists.umanitoba.ca/mailman/listinfo/aquaculture-impacts.

The schedule of workshops then will be:
Workshops by the end of June 2004 end of September 2004 and a final conference in November 2004. The first two workshops a selected number of people will be invited. The goal of the June 2004 workshop is to pin down the corners of 3-4 promising different design strategies. Between the two workshops three or four invited essays will have to be written in where the designs are worked out. The September workshop will be used to deepen and broaden the proposals. The November conference will be a

discussion of the four proposals starting from invited reactions, with the aim to come to recommendations for research and development.
The next two months will also be used to hunt for finances. By January/February we hope to be able to tell you more about the terms and conditions that we will be able offer to those invited for the workshops. Advise on financing sources is of course always welcome.

Hope to hear from you soon,

Kind regards,

Paul van Zwieten

Appendix 4: List of persons contacted and reactions

First mail		Second mail					
sent	reacted	sent	reacted	**Names**	**E-mail**	**Address**	**Remarks**
s	r	s		Akke van der Zijp	Akke.vanderZijp@wur.nl		Ontwerp atelier in veeteeltsystemen in Nederland. Interessant voor uitwisseliong van ervaring hiermee
s	r	s	r	Albert Tacon	AGJTACON@aol.com	Hawai consultant	
s	r	s	r	Amir Neori	aneori@shani.net		from Israel: one of the persons with the most advanced knowledge and understanding of land-based integrated aquaculture;
s				Anthony Farmer	ASDFarmer@aol.com	Prime Farm, Whitchurch Canonicorum, Bridport, DT6 6RP Dorset United Kingdom Kontakt person: Bernadine de Silva Tlf: +44 1297 489100 Fax: +44 1297 489081	garnalen, visserij
s	r	s		Arjo Rothuis	a.j.rothuis@minlnv.nl	Ministerie van LNV; Directie der Visserijen'Postbus 20401; 2500 EK Den Haag Tel. nr. 070 – 3793911; Telefax 070 – 3815153;	
s	r	s	r	Barry Costa Pierce	bcp@gso.uri.edu'	University of Rhode Island, focus on ecological and social impacts	
s	r	s	r	Bill Silvert	ciencia@silvert.org		theoretical ecologist; see: http://Bill.Silvert.org
s	r	s		Carel ter Kuile	info@ledafish.com		Handel in vis met Ethiopie; consultant LEDA fish. Heeft brief doorgestuurd naar Kees Lankester
s	r	s	r	Carl Folke	carl@beijer.kva.se		
s	r	s	r	Courtney Hough	secretariat@feap.org	30 rue Vivaldi, B-4100 Boncelles Belgium; Tel'+32 4 3382995 Fax +32 4 3379846	General secretary Federation of European Aquaculture Producers
s		s		Denis Lacroix	denis.lacroix@ifremer.fr	IFREMER	
s	r	s		Doris Soto	dsoto@uach.cl		
s	r	s	r	Esther Luiten	Luiten@stt.nl		Stchting Toekomst Beeld der Techniek – Ocean Farming project
s				Eva Roth	er@sam.sdu.dk		
s		s		George Chamberlain	georgec@integra.prserv.net		
s	r	s		Gert-Jan de Graaf	degraaf@nefisco.org	Nefisco Foundation; Lijnbaansgracht 14c; Amsterdam'The Netherlands; +31 20 624 99 63	Consultant; recente ervaring m.n. in ZO Azie maar ook Afrika

s	r	s		Hans Komen	Hans.Komen@wur.nl		Sefabar, geneticist
s	r	s		Hans van Weerd	vanweerd@artis.nl		Direkteur Artis
s		s		Hans van Zon	Hvanzon@cs.com		
s	r	s	r	Hans Vink	Hans.vink@nutreco.com	(Nutreco)	
s	r	s	r	Harald Rosenthal	haro.train@t-online.de		Aquacultuur/mariene ecologie Institut fur Meereskunde
s				Ian Davies	i.m.davies@marlab.ac.uk		
s	r	s	r	Ingvar Olsen	yngvar.olsen@vm.ntnu.no	Trondhjem Biological Station, Norwegian University of Science and Technology (NTNU)'N-7491 Trondheim, Norway; Phone: +(47) 7359 1592 Home: +(47) 7397 8407; Fax: +(47) 7359 1597	Reseracher: very interesting ideas on utilising lower tyrophic levels in the aquaculture food chain (fishing calanoid copepods; mussels) and artificial upwellings
s	r	s	r	James Muir	jfm1@stir.ac.uk	Stirling Aquaculture, Institute of Aquaculture, University of Stirling, Stirling FK9 4LA, UK. Telephone: +44 (0)1786-467900, Fax: +44 (0)1786-451462	Director Stirling Aquaculture; much experience in Mediterranean Aquaculture
s				Jan Stel jh.	stel@icis.unimaas.nl	P.O. Box 6166200 MD Maastricht The NetherlandsTel. 043 388 3943; +31 (0)43 3882662; +31 (0)43 3884916	Professor in “Ocean Space and Human Activity” (50%) and leader of the Water section within ICIS. Senior policy maker (international affairs polar research and global monitoring activities) at the NWO,
s	r	s		Jason W. Clay	jason.clay@wwfus.org		Clay Vice President Center for Conservation Innovation World Wildlife Fund
s				Jayampathy. Samarakoon	samarakoon@eureka.lk	Wetland IRMP'Central Environmental Authority'104 Robert Gunawardena Mawatha'Battaramulla'Tel: 94-1872300'Fax: +94-1872300	aquatische ecology, wetlands, kleinschalige visserij
s	r	s		Johan Verreth	johan.verreth@wur.nl		
s	r	s	r	Jos Pet	jpet@tnc.org		Programma co-ortdinator The Nature Conservancy: Marine Parks – Komodo aquaqculture facility
s	r	s	r	Jurgenne Primavera	nykjprim@skyinet.ne		Philippines, UniversityProfessor
s	r	s	r	Jurgenne Primavera	jhprima@aqd.seafdec.org.ph		
s				Kees Lankester			?
s	r	s		M.J. Phillips,	Michael.Phillips@enaca.org		Supports NACA in addressing environmental sustainability and management issues in the Regional Work Programme, and in the development and management of technical assistance projects for NACA members.
s	r	s		Marc Verdegem	marc.verdegem@wur.nl		

s		s		Martin Scholten	Martin.Scholten@wur.nl		Directuer RIVO, afkomstig uit TNO. Heeft ideeen over herinrichten kustzones en aquacultuur mogelijkheden
s	r	s	r	Max Troell	max@beijer.kva.se		from Sweden: a key person in terms of ecological and economic reflections on aquaculture (see attached paper we just published in Aquaculture);
s	r	s	r	Michael New	Michael_New@compuserve.com	president EAS	
s	r			Michael Phillips		NACA aquaculture expert, Bangkok	
s	r	s		Nils Kautsky	nils@system.ecology.su.se	Department of Systems Ecology; Stockholms University SE-106 91 Stockholm; Stockholm'Phone:+46 (0)8 164251 Fax: +46 (0)8 158417	Professor of Marine Ecotoxicology at the Department since 1989. Deputy Director of the Beijer International Institute of Ecological Economics at the Royal Swedish Academy of Sciences since 1997. http://www.ecology.su.se/staff/personal.asp?id=15
s	r	s		Patrick Dugan	pjdugan@dial.eunet.ch	Regional Research Center for Africa and West Asia P.O. Box 2416 Cairo, Egypt	Deputy Director General - Africa and West Asia – ICLARM; would in principle take part in the whole process and wishes to draw in other collegues from Asia and Africa (and elsewhere in Worlfish)
s	r	s		Patrick Dugan	p.dugan@cgiar.org		
s	r	s		Patrick Sorgeloos	patrick.sorgeloos@rug.ac.be	Laboratory of Aquaculture '& Artemia Reference Center 'University of Ghent 'Rozier 44, B-9000 Gent, Belgium'Fax +32-9-2644193	Professor Aquaculture Gent
s		s		Pedro Bueno	Pedro.Bueno@eNACA.ORG	NACA Coordinator Suraswadi Building, Fisheries Department Compound, Kasetsart Campus,Jatujak, Bangkok; Kasetsart PO Box 1040; Bangkok 10903 Telephone +(66-2) 561 1728/9 Fax +(66-2) 561 1727 E-mail	NACA director
s	r	s		Peter Burbridge	p.r.burbridge@newcastle.ac.uk		coastal resources development person and coastal
s	r	s		Peter Burbridge	Peter_burbridge@yahoo.co.uk		zone manager/scientist – ICES,/LOICZ _University of Newcatsle.
s	r	s	r	Peter Mous	pmous@tnc.org		Scientist workinf for The Nature Conservancy see Jos Pet
s	c			Peter Nijhof	plnijhoff@hetnet.nl	functie: : telefoon: 035 - 6214748	oud-directeur Natuur & Milieu interessegebied: Water
s				Pier Vellinga;	secr@ivm.vu.nl	SENSE De Boelelaan 1115 '1081 HV Amsterdam; Nederland 'www.sense.nl/ Telefoon 020-4449555 Telefoon: fax 020-4449553	Director of the Institute for Environmental Studies (IVM) VUA scientific director of the SENSE Research School (Socio-Economic and Natural Sciences of the Environment),(GEF, UNEP, etc)

s				Roel Schouten	Schouten@mozart.inet.co.th	Seatec International - Consulting Engineers, Bangkok 972/1 Vorasubin Bldg; PO Box 8-101; 10320 Bangkok; Thailand Telephone (+66) 2 - 641 42 14 Facsimile'(+66) 2 - 641 42 19 'Internet www.skm.com.au/environmental/	garnalen, visteelt, ecology
s				Roel Schouten	klooby@skm.com.au		
s				Ron Zweig		World Bank aquaculture expert, Washington DC	
s	r	s	r	Rudy Rabbinge	Rudy.Rabbinge@wur.nl	Haarweg 333, 6709 RZ Wageningen +31 (0)317 483988 / 482141	Asked by UN Secretary Kofi Anan to develop ideas for africagriculture. Interesting article in Spil: useful ideas for Aquaculture
s				Selina Stead	s.stead@abdn.ac.uk	University of Aberdeen	
s	r	s		Thierry Chopin	Tchopin@unbsj.ca	University of New Brunswick	
s	r	s		Tom Hecht	t.hecht@ru.ac.za	Rhodes University	
s				Uwe Barg	uwe.barg@fao.org FAO FIRI		FAO Fisheries Department, implementing Code of Conducts in shriomp farming; secretary sub-committee aquaculture EIFAC
s	r	s	r	Yngvar Olsen	Yngvar.olsen@bio.ntnu.no		
				Yves Bastien	bastieny@dfo-mpo.gc.ca		from Canada: the Commissioner for Aquaculture within the Canada Dept. of Fisheries and Oceans (a government and regulator perspective);
				Adi Hanafi	gondol@singarja.wasantara.net.id	62-812-3650155	
	-			Björn Mirsed	homeoffice@gaalliance.org	Global Aquaculture Alliance 5661 Telegraph Road, Suite 3A -- St. Louis, Missouri 63129 USA Telephone: 314-293-5500 -- Fax: 314-293-5525 -- E-mail:	
	-			Christian Gamborg	chg@fsl.dk	Centre for Bioethics and Risk Assessment; Danish Forest and Landscape Research Institute; Hørsholm Kongevej 11; DK-2970 Hørsholm; Denmark 20Tel.: +45 45 76 32 00 Fax +45 45 76 32 33; E-mail:	SEFABAR contact via Hans, bioethicus
				Claude Boyd	_	Auburn University, technical expertise on a range of species	
				David Rideout	rideoutcaia@aquaculture.ca		from Canada: the Executive Director of the Canadian Aquaculture Industry Alliance (an industry perspective who will be glad to link academics and industry reality!).
				Ketut Sugama	sugama@indosat.net.id		
	-			Lester Brown	epi@earth-policy.org	Earth Policy Institute'1350 Connecticut Ave. NW 'Washington DC 20036'Ph: 202.496.9290 Fax: 202.496.9325	Director Earth Policy Institute

	-			Mario Pedini	mario.pedini@fao.org	FAO,Inland Water Resources and Phone: +39 06 57056279 Fax: +39 06 57053020 Email:	Aquaculture Senior Adviser (Aquaculture Development)
				Mike Rimmer	RimmerM@prose.dpi.qld.gov.au		
				Paul Holthus	paul.holthus@aquariumcouncil.org	www.aquariumcouncil.org	
				Peter Scott	plglscott@cs.com	International Marine Alliance/Marine Aquarium Council/TNC Project	
				Philip Notten	p.vannotten@icis.unimaas.nl		
				Reid Hole	_	Nutreco Cie	
				Roger Pullin	karoger@pacific.net.ph		
				Rohana Subasinghe	Rohana.Subasinghe@fao.org	FAO aquaculture lead, Rome	