FISHERIES, SUSTAINABILITY AND DEVELOPMENT

Fifty-two authors on coexistence and development of fisheries and aquaculture in developing and developed countries

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FOREWORD

Fishes constitute a major part of the aquatic ecosystems that cover about 2/3 of the world. Fisheries provide nutritious food of major importance as well as livelihoods, export incomes, recreation, etc., and could play an important role for development and poverty reduction. However, donors and developing countries have failed fully to take advantage of the potential. Fish stocks are under pressure in most parts of the world. Capture fisheries cannot satisfy the increasing demand for fish and shellfish. Responsible and profitable aquaculture has to be promoted, and changes are urgently needed to make the fisheries sector more sustainable, both ecologically and socio-economically.

How can the unsatisfying status of so many valuable fish stocks all over the world be improved, and the increasing demand for fish and shellfish met in the long run? How can fisheries in developed and developing countries progress in harmony, and at the same time contribute to sustainable development? These and similar questions are the object of a keen international discussion. This book aims at contributing to this discussion, with topical scientific data and an overview of current knowledge. The issue of fisheries is wide, complex and partly controversial. Therefore, a book like this has to present subject matters from different angles. Special attention is paid to fish stock conservation and to fisheries in developing countries.

The Royal Swedish Academy of Agriculture and Forestry recently published an anthology on coexistence and development of agriculture in developing and developed countries, titled *Agriculture, trade and development – Toward greater coherence*. The book was issued in Swedish in 2006 and in English in 2008 (revised version). It was very well received and soon discussions started within the Academy about the possibilities to publish a similar book on fisheries. The original proposal came from Mikael Cullberg, then at the Swedish Board of Fisheries.

The project was funded by the Swedish International Development Cooperation Agency (Sida), the Academy, the Swedish Board of Fisheries, the County Administration of Västra Götaland and the A W Bergsten Foundation. In addition, substantial voluntary work was devoted to the planning, writing and editing of the book. The Academy wishes to express its sincere gratitude for all contributions to the project. A special thanks is

extended to all the authors, who kindly and enthusiastically provided their expertise and experience to the project – on top of all their other commitments – thereby making the book possible.

An editorial committee was set up to run the project. It consisted of Academy Fellows Prof. Per Wramner (chairman) and Prof. Hans Ackefors, with Mikael Cullberg (County Administration of Västra Götaland) as secretary, as well as Antonia Sanchez-Hjortberg (Swedish Board of Fisheries), Joacim Johannesson (Swedish Board of Fisheries) and Johan Sundberg (Sida). Per Wramner, Hans Ackefors and Mikael Cullberg acted as editors of the book, and Ylva Nordin was responsible for the layout. A reference group consisting of representatives from various organisations in the fields of fisheries and environment followed and commented on the work continuously.

The book is aimed at a broad audience with an interest in fisheries in a wide sense, such as politicians, social movements, universities, government agencies, fishers, fish farmers, fisheries organizations and other stakeholders. Several chapters are also appropriate as course literature in various fields of study. The book neither attempts to provide unequivocal answers, nor does it outline definite development paths. Instead, it is aimed at presenting an important and complex area from the perspectives of different expertise and experience. Nevertheless, the final chapter attempts to summarize certain conclusions from the various contributions and discusses possible ways forward.

Åke Barklund
Secretary General and Managing Director
Royal Swedish Academy of Agriculture and Forestry

FEED – THE KEY TO SUSTAINABLE FISH FARMING

Anders Kiessling

Summary

This chapter discusses fish farming in terms of feed, feed resources and nutrition physiology. Feed is both the single largest cost to the farmer but also the major factor affecting the environmental impact of fish farming, including production and transport of the feed as well as effluence from the farm during production. However, the same arguments apply to all intensive animal production. On the one hand, fish are certainly our most efficiently farmed animal in the sense of nutrient utilisation and farming space required. On the other, intensive fish farming offers challenges not faced by terrestrial animal farming in minimising the environmental impact. After a short definition of fish farming, this presentation deals first with fish versus terrestrial farmed animals and secondly the farming of carnivorous cold water versus omnivorous/herbivorous warm water fish species. The fact that the carrying capacity of all ecological systems is limited is gaining acceptance also outside the world of natural science, as is the insight that most plant- or animal-based feed sources suitable for farmed animals, including fish, are also suitable for human consumption. This insight leads to the realisation that the only sustainable alternatives are scenarios in which farmed animals become net contributors by a transfer of "non-human" food resources into human ones in an ecologically sound way. The final part of this section is therefore dedicated to feed sources with the potential of transformation of "non-human" or "low human interest" food sources into high-quality human food via farmed fish.

Fish farming systems

Using feed as the denominator, most researchers tend to define fish-farming systems in terms of the type of energy fed into the system. Early fish farming was based on photosynthesis in phytoplankton living in the same water as the fish. CO_2 and water were transformed into nutrients and tissues like protein, fat and bones via glucose. Compounds such as nitrogen, phosphorus, calcium and sulphur all occurred naturally in the system as a result of plant decomposition and minerals eroding from the soil. Herbivorous and omnivorous species, like those found in the families of tilapia (*Oreochromis* spp and *Tilapia zillii*, Africa) and carp (order *Cyprinidae* which includes many families, Asia), have naturally adapted to such aquatic food webs, feeding from different tropic levels as phytoplankton, zooplankton and their predators. A mix of species of these two large families of fish that utilise different niches in such food webs are still commonly used in so-called "polycultures". Such systems, termed *"extensive" systems*, tend to be most productive in warm climates, while fish farmed in temperate regions obtain nearly 100 percent of their energy from external, modified and refined sources and are therefore termed *"intensive" fish farming* and are exclusively based on monocultures. The sun is the ultimate source of the external energy in both cases, but the difference lies in where this energy is trapped in the ecosystem.

We also classify fish farming, from a climate or feed perspective, as either *tropical* or *coldwater farming*, sometimes also termed *omnivorous/herbivorous* versus *carnivorous* fish nutrition. Historically, these terms also referred to extensive and intensive farming systems, described above, since cold-water farming, in contrast to warm-water farming, is dominated by carnivorous fish species exclusively dependent on external food sources. Improved productivity in the tropical freshwater systems was originally achieved by adding nutrients to the system. Such systems, normally termed semi-intensive, could in their simplest form be achieved by ruminants grazing on the land surrounding the ponds, later advancing to utilise faeces from monogastric animals (pig, poultry, man) living close to the pond or effluents from agricultural or human societies including more complicated systems with animal or human housings literally built over ponds, in order to allow the droppings to function as food for the fish and fertiliser for the endogenous food web of the pond. Today it is more and more common to use low quality feed, ranging from raw plant components, such as peas, directly into the pond, or in more advance cases simple grained and pelleted products with low protein content. Such semi-intensive systems often include some mechanical improvements in order to aid gas transfer between air and water. Also the opposite, i.e. the effluent of the fish farm, is often utilised as fertilisers of plant or invertebrates (filtering) in low intensive systems.

The productivity of such systems meets local consumption including nearby cities. The modern global food market has, however, put a completely different pressure on logistics and profitability, in terms of generating a surplus cash flow, which becomes possible only by an intensified production. Today we see a rapid transformation of production strategies in these traditional extensive warm water systems towards an intensity and technology well known from modern salmonid cold water farming, including fabricated high protein/energy and highly digestible feeds, selective breeding and even genetic modification of the fish (FAO 2009).

An alternative tropical system hopefully capable to match the "salmonid cage and tank" technology is now evolving. It combines the technique of the traditional extensive pond system with the use of industrial feeds and modern technology, including breeding programmes. These systems are often referred to as *"green water" farming*,

Figure 1. Modern "green water" freshwater pond farming of tilapia (*Oreochromis* spp.) in Southern China.
The photo at top right shows mobile green houses necessary to maintain high water temperatures during the cold season. Bottom right photo shows a tilapia from the 16th generation of Genomar's breeding program. Photos provided by Dr. Sergio Zimmerman, Akvaforsk Genetics AS, Norway.

distinguishing them from tank and free floating cages, which are referred to as *"clear water" farming*. Tilapia, but also shrimps, are currently the preferred species for these systems. Figure 1 shows a typical "green water" set-up using solar-powered greenhouses. The reference to the colour green naturally refers to the occurrence of phytoplankton in the water. These systems, handled correctly, have a high production potential with two distinct advantages over the "clear water" systems. *First*, all the food introduced but not eaten by the fish will be incorporated into the "natural" food web of the pond and thereby offering the fish a second chance. In fact, it has been well demonstrated that green water systems offer the possibility of efficiently using feed, with a high level of plant sources with poorly degradable complex carbohydrates not otherwise available to higher organisms and a low protein content (< 30 percent DW[1]).[2] Not only is uneaten feed circulated by the micro-flora and fauna to the fish, but also nutrients with low digestibility are released to the micro-organisms through the faeces of the fish. The *second* advantage of "green water" over

1. DW = dry weight.
2. S. Zimmerman, personal communication.

"clear water" systems is a "pro-biotic" effect of the micro-organisms in the water. It seems likely that pathogenic micro-organisms are at a disadvantage if the correct pond environment is maintained (Pulz and Gross 2004). Drugs as antibiotics are less used in "green water" systems.[3] Diseases and pharmaceuticals are negative for fish growth, environment as well as for the farmer's finances. The drawback of the "green water" system is the need for warm water, e.g. tilapia thrive at temperatures above 29°C. Solar-powered green houses have recently extended the economic production range further to the north and south as far as southern China and Brazil, respectively.[4]

Another, but less well-known, difference between cold water and traditional tropical systems concerns the product quality in the form of healthy "fish fat", normally termed n-3 (omega-3) HUFA.[5] What is commonly called "fish fat" is only to a small proportion produced by the fish. In fact the health-promoting, long-chain fatty acids of the n-3 type normally associated with fish (EPA and DHA)[6] are mainly synthesized by marine and cold fresh water phytoplankton and then transported up the food chain. In the tropical zone phytoplankton in freshwater, and thereby also the fish, is dominated by the same type of fats as found in plant oil, namely of the n-6 (omega-6) family. If high content of marine fat is desired in the flesh of any farmed fish, it has to be added to the diet. Table 1 shows the fatty acid composition in flesh of different species of farmed and wild fish. At present "fish fat" is added to the diet in the form of marine oils. However, this involves sustainability issues, as fish oil is partly obtained through non-sustainable fisheries. New sustainable sources of marine fats are therefore urgently needed (see also Figure 4), and are focal points for the feed industry. Marine oil from artificially reared micro-algae is already in use, but the technology is costly. Another potential source is genetically modified plants (GMO), which are currently being tested on a laboratory scale with some success. Already GMO rape seed contains high levels of EPA while introduction of genes stimulating synthesis of DHA seems to require further research. Another approach towards enriching the fish flesh with these fatty acids, healthy to man, is to stimulate the endogen capacity of the fish itself to produce EPA and DHA from other fatty acids readily available in some plant oils. Trattner *et al.* (2008) demonstrated close to a doubling of DHA in rainbow trout flesh after feeding a mixture of sesame and rapeseed oil, a result noted with interest by the industry.

Development of fabricated diets

In the early days of salmonid farming, the feed normally consisted of raw animal liver, chopped fish, squid and other animal protein and fat sources, such as egg yolk.[7] Feeding then gradually evolved to include offal, different fish products and dry meals to form moist (water content > 70 per-

3, 4. S. Zimmerman, personal communication.

5. HUFA= highly unsaturated fatty acids with carbon chains from 20 carbons and upwards, not including n3 from plant oils.

6. Eicosapentaenoic acid, EPA, and Docosahexaenoic acid, DHA, are fatty acids with 20 and 22 carbons and 5 and 6 double bounds, respectively, of the n3 family and is grossly described important, respectively, in the hormone and nervous tissue formation of humans.

7. Eva Bergström, personal communication. Eva Bergström also made major contributions to the development of dry feeds for young stages of salmon at her work at the Salmon Research Institute, Älvkarleby, Sweden.

cent) and semimoist (water content > 30–40 percent) pellets. Moist pellets in fact dominated the feeding of adult stages of salmonids as late as in the 1980s, while dry pellets (water content < 10 percent) were developed for start-feeding and young stages[8] long before it became the dominating feed type for adult fish. Salmonids have large eggs and thereby larvae with a well-developed digestive apparatus already at start feeding, which facilitates the use of fabricated diets throughout the

Table 1. Examples of fat content and relative level of the omega 3 fatty acids EPA and DHA in a consumer portion[a)] of a few selected farmed and wild fish.

Species	Fat content g/100g)	EPA % of lipid	DHA % of lipid	EPA (g/100g)	DHA (g/100g)
Farmed salmon[b)]	10–23	8.5	15	0.8–1.6	1.4–2.3
Farmed salmon, given 50:50 % fish:plant oil	10–20	4.2	7.5	0.4–0.8	0.7–1.1
Wild Atlantic salmon	8–12	4.4	11	0.3–0.5	0.8–1.3
Wild Chinook *(O. tsawytscha)*	11	3	8	0.3	0.8
Wild Sockeye *(O. nerka)*	8	4	8	0.3	0.6
Wild Coho *(O. kisutch)*	6	4	11	0.3	0.6
Wild Pink *(O. gorbuscha)*	5	5	13	0.3	0.8
Wild Chum *(O. keta)*	4	3	8	0.15	0.4
Farmed Raibow trout, portion sized (300–800 g)	4	6	18	0.2	0.7
Farmed Rainbow trout, large (3–5 kg)	10	4.5	13	0.4	1.1
Farmed Arctic charr[c)]	12–16	11	15	1.0–1.7	1.7–2.3
Farmed cod	1–1.5	12	35	0.1	0.5
Wild cod	0.5–1	16	35	0.05–0.1	0.1–0.2
Carp	5	4	2	0.2	0.1
Tilapia	<1	16	35	0.005–0.1	0.1–0.2

The underlying rational for the marked variations in lipid content, also within a species, is a combination of factors as diet energy, life stage, fish size, strain and other less defined factors in the environment of the fish. Diet composition[d)] and tissue fat content[e)] are without rivalry the two most important factors setting the total content of EPA and DHA (as well as the majority of all other lipid soluble components) in the fillet of fish. Another important error factor to consider when comparing data from different studies is trimming/skinning (trimmings contain high levels of adipose tissue and the skin is attached to the fat rich red muscle). A 50-percent reduction in fillet fat content is reported after skinning of Pacific salmon[e)]. The tabulated data are based on a mix of our own work[f)] and of others[e), g)].

a) Excludes extra muscular adipose tissue and includes red and white muscle.
b) Scottish and Irish farmed Atlantic salmon tend to be found in the lower range, while farmed Norwegian and Canadian West coast Atlantic salmon are found in the upper range. Farmed Pacific salmon are found in the lower upper range.
c) In non skinned Arctic charr fillets, from fish fed high lipid diets (> 25 percent, DW) fillet fat content can exceed 20 g/100g.
d) Waagbø, R. *et al.* 2001.
e) Ikonomou, M.G. *et al.* 2007.
f) Johansson, L. *et al.* 1995. Johansson, L. *et al.* 2000. Jonsäll, A. 1995. Kiessling, A. *et al.* 2001. Kiessling, A. *et al.* 2004.
g) Mørkøre, T. *et al.* 2001. Jana Pickova, Magny Thomassen, Lars Ove Eriksson, personal communications. Information in official data bases (Swedish National Food Administration, Norwegian National Institute of Nutrition and Seafood Research, USDA, Nutrition Data Laboratory and Canadian Nutrient file).

8. Eva Bergström, personal communication.

entire life cycle. Control of the complete life cycle, including diets, was a new invention in the history of fish farming. Salmonids thereby became the first fish species, in which man had full control of all aspects of the entire life cycle, a prerequisite for optimizing both production and the organism as such, including specific breeding programmes. The development of salmonid farming led the way in the now rapidly escalating transformation of fish farming from an activity that either utilized "on growth" of wild fish or passively mimicked the natural conditions of wild fish, into an activity fully commanded and controlled by man. Fish farming hereby parallels the process of domestication seen in all terrestrial farmed animals, in which the development of formulated diets has been a prerequisite. In the field of "aquafeeds" this development is characterized by the transition from a diet using the same nutrients source as the wild fish, to an adequate diet independent of nutrient source, be it of animal, plant, micro-organism or synthetic origin.

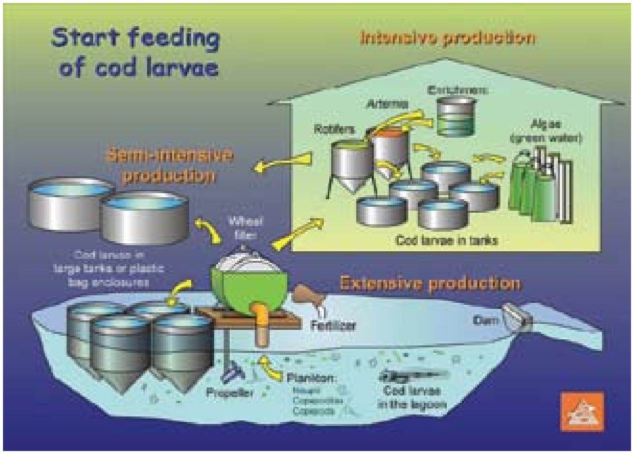

Figure 2. A schematic picture showing different types of cod larvae production ranging from extensive (bottom right), allowing the larvae to feed only on natural production, to intensive fully controlled systems with artificially enhanced live feed (top). (Van der Meeren, T. and Naas, K.E. 1997. *Reviews in Fisheries Science* 5: 367–390.)

During the 1970s, feed manufacturers started large-scale production of salmonid feeds. At first, this was a very diverse industry but it gradually became completely dominated by a few multinational companies. The same process took place at the turn of the century for Mediterranean farmed species, and is currently repeating itself in the intensification of tropical fish-farming systems. The use of moist diets is still common for many marine species, consisting of chopped fish and squid, but major environmental concerns have been expressed against this practise. During the past thirty years, the research in nutrition of marine fish has, in parity to the early development of salmonid nutrition, focused on fabricated diets to be used in intensive systems already from start-feeding. In Figure 2 the technical evolution of Norwegian cod farming is shown, illustrating both the transformation from an extensive to an intensive system and the problem of start-feeding in species with small larvae, typical of many marine and freshwater species. The development of start-feed programs, together with artificial reproduction has formed the basis for the explosion we now see in the intensive farming of several marine and freshwater species characterised by small larvae with complex nutritional needs during their early life stages. However, a labour intensive and economically costly start-feeding period with live feeds of rotifers and copepods and/or enriched artemia (Figure 2) is still necessary for most of these fish species.

The advantage and disadvantage of farming in water compared to on land

When we consider feeds for farmed fish, independent of whether it is a warm water herbivore or a cold water carnivorous fish, there are a few physiological facts that we need to be aware of. As already pointed out, fish are without comparison the most efficient protein-transforming higher animals ever farmed by man. This is as true for modern salmon farming as it is for traditional poly-culture of tropical fish. A very gross comparison between energy and protein efficiency in mammal, fowl and fish is shown in Table 2.

A second interesting fact is that fish assimilate protein without methane production, as the digestive system of fish is low in micro-organisms in comparison with most terrestrial animals, where ruminants represent the most extreme case. This high metabolic efficiency and the absence of a well-developed micro-flora is simply a result of evolution in water. The main advantages in rearing fish compared to land living animals can be summed up as follows:

Firstly, water has high conductivity. By always adapting the temperature of their body to that of the water, fish do not need to create enormous layers of fat for insulation as marine mammals do. Nor do fish need to use energy specifically for heat production when the waste heat of digestion, metabolism or muscle contraction is not sufficient to maintain a steady body temperature. In fact an

Table 2. Comparison between different types of fish and terrestrial production animals in diet carbo-hydrate content, energy and protein retention.[9, 10]

	Fish					Fowl		Pig	
	Salmon	Rainbow trout	Chanel catfish	Common carp	Indian carp	Broiler	Hen	Slaughter	Sow/Wild
Carbohydrate of diet (% DW)	10	15	25	30–40	20–30	50–60	60–70	55–65	70–80
Proportion of total energy requirement used to maintenance in actively producing animals (%)	8					61	67	41	67
Retention gross energy in edible part (%, meat or milk)	30–35		15–25*			12	–	16	< 16
Retention gross protein in edible part (%)	30–40		20–30*			18	–	13	< 13

*Due to lower slaughter yield compared to salmonids (≈ 20–30 percent and 60 percent respectively).

9. Waagbø, R. *et al.* 2001.
10. Austreng. E. 1994. Birger Svihus, personal communication. Svihus, B. 2007. Thodesen, J. *et al.* 1999. Grisdale-Helland, B. and Helland, S.J. 1997. McDonald, P. *et al.* 2002. T. Åsgård, Nofima Marine, Norway, personal communication.

outdoor-raised pig can spend up to 40 percent of ingested energy on heat production alone, while a decrease of 1°C in the indoor temperature of a broiler barn increases food consumption by up to 10 percent (McDonald *et al*. 2002).

Secondly, most fish produce an abundance of eggs which naturally reduce the resources allocated to keep a large parental generation.

Thirdly, water has unitary density. This makes excessive fat accumulation impossible (fat tissue has a density of 0.8, the so-called "cork effect") and favours energy deposition in the form of protein, i.e. muscle. Not only has muscle a density close to water and is therefore weightless, but it also has the advantage that it provides its own means of mobility. In other words it is no disadvantage to accumulate excessive energy depots in the form of protein if you live in water, while large fat depots, as seen in mammals, would be detrimental in fish, which have a very thin and light bone structure adding very little to the weight (density) of the fish. In contrast to fat, protein stored as muscle consists of water at a ratio of 1:4; i.e. one gram of protein is accompanied by at least four grams of water, increasing body weight roughly five to six times as much, as if the same dietary energy had been stored as fat. Size, a strong survival value also in the aquatic environment, can thus be achieved without the negative consequences of gravity. Consequently, fish are the only vertebrates that can afford life-long muscle growth by cell proliferation. In all terrestrial animals muscle proliferation (formation of new cells) ceases at birth and muscle growth thereafter consists only of enlarging existing muscle fibres, i.e. the number of muscle fibres present at birth is an important factor limiting maximum growth of land animals. All farmed species of fish, in fact nearly every species of fish, have the ability to form new muscle fibres throughout life, an ability that bodybuilders can only dream of, i.e. unlimited muscle growth. This contrasts sharply with animals living on land, where every gram of body weight has to be carried against the constant force of gravity, an obvious fact when we examine examples of human efforts to increase muscle growth in terrestrial animals, as is best illustrated by the extreme of the extremes, the Belgian Blue strain of cattle. Naturally, fat tissue, with its high energy value per unit weight and absence of associated water, has been favoured during terrestrial evolution in animals in need of endogenous energy stores, while protein has been favoured in the aquatic environment.

Finally, living in water offers an easy route to dispose of nitrogen, the by-product of protein and to some extent also purine catabolism. When amino acids are deaminated, the amino group is released as a water-soluble ammonium ion (NH_4^+). The ammonium ion is in equilibrium with ammonia (NH_3), a very toxic compound. Fish can easily reduce the level of ammonia by excreting ammonium ions via the gills and thereby avoiding the risk of toxic endogenous levels, while terrestrial animals reduce the amount by transferring the nitrogen from protein to urea or uric acid (poultry) and then excreting it via the urine or faeces (poultry), an energy-intensive process.

From an environmental point of view, fish are hereby at a disadvantage to terrestrial animals, as it is nearly impossible to collect these eutrophicating substances, nitrogen and phosphorus, as soon as they are dissolved in a larger water volume, while on land we can separate the urine/faeces and even chemically catch dissolved phosphorus and thereby recycle them back into plants, at least in theory. The route to decreasing nitrogen and phosphorus loss during fish farming can be separated into three levels:

Firstly, reduction of feed waste, which is accomplished through improved feeding protocols (where, when and how), more appetising diets and techniques to measure appetite and thereby know when to stop feeding (e.g. by video) or recycling or collection of uneaten feed.

Secondly, increasing digestibility and durability of the digesta and faecal matter, respectively, and thereby increasing uptake of nutrients during digestion and facilitating removal of faecal matter by filtration before the effluent water enters the surrounding water. Increased faecal matter durability will also increase the fraction eaten by organisms in the ecosystem surrounding the farm and thereby enhance growth in the local food web, allowing recapture of the nutrients in clear water systems by harvesting of e.g. wild fish, farmed/wild mussels and plants. In green water systems the farmed fish will recapture the nutrients directly by eating the organisms as feed.

Finally, by affecting the metabolic efficiency of the nutrients both by feed source, feed composition, by selecting favourable farming locations and by genetic selection, where individuals with high protein retention would be the target. One could include a fourth method, biological purification, which at present only is feasible in closed (recirculation) or low intensity systems. In these systems the effluent water passes a biological filter of nutrient binding micro-organisms after mechanical filtration. Such a biological filter can be organised in several ways, for example, as a free floating suspension, where the micro-organisms (algae/plants) later are trapped by filtering organisms (e.g. bivalves), as a bed of micro-organisms attached to a solid substrate, where they later can be mechanically harvested, or so that the effluent water can be used to irrigate plants.

Reduction of nitrogen loss by nutrition

The reduction in loss of nutrients from commercial cold water fish farming over the last thirty years, by improvement in feed regimes and feed composition is illustrated in Figure 3. Changes in feed composition for salmon during the same time period is illustrated in Figure 4. In the wild, salmonids prey on organisms higher in protein than fat. Naturally, early fabricated diets mimicked this. With increasing quality of fishmeal and thereby biological value (see below), protein was gradually replaced in salmonid feed by fat (oil), yielding energy rich and "low" protein diets (Figure 4). This fat and protein was originally from pure fish oil and fishmeal, but due to reduced availability of these commodities, followed by increases in price, 40–50 percent of both fish oil and fishmeal is now replaced by plant oil and plant protein in diets to adult salmonids. Of course, such a switch in feed sources is associated with its own problems, but an amino acid from plant is identical to the same amino acid from fishmeal. However, the amount of the different amino acids (normally termed amino acid profile of a protein) and other plant specific substances (see below for more details) are the problems that demand specific focus by the feed manufacturer, in order to assure proper function of the diet independent of nutrient source. Replacement of marine fat or oil in the diet is much less complicated because the need of the fish for the special fatty acids (EPA and DHA) of marine fats is much lower than the amounts added in modern salmon diet. A large portion of the dietary fat may therefore be replaced by any fat with a high enough melting point to

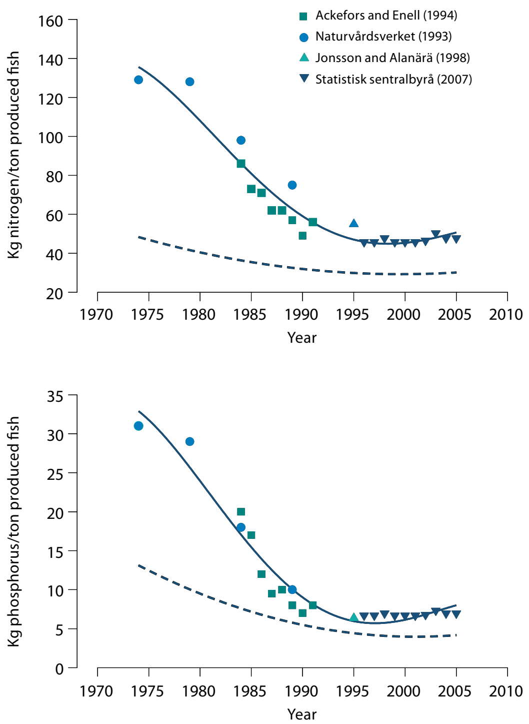

Figure 3 Historical changes in calculated and theoretical nitrogen and phosphorus effluents from Swedish fish farms. The solid line is based on official reports of feed sold and fish produced. The dotted line represents the theoretical effluent based on calculated feed conversion (kg of feed used per kg of produced fish).[11] The decrease in the reported data is mainly an effect of improved feed conversion, while the decrease in the dotted curve most likely represents in the case of nitrogen an improved retention and in the case of phosphorus a decrease in phosphorus content of the feed.[12]

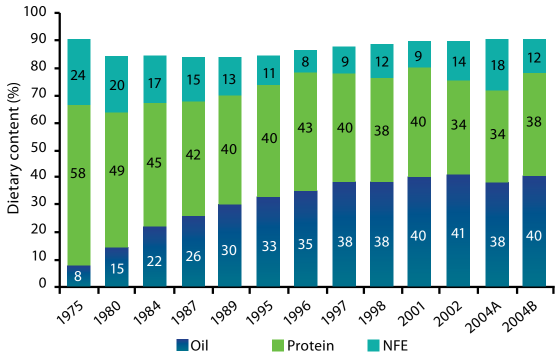

Figure 4. Changes in nutrient composition of fabricated salmon feed over the last 30 years. The over all trend is a replacement of protein by oil. Originally only fishmeal and fish oil were used as a source, but today 40–50 percent of both protein and oil originates from plant sources. The 2004A and 2004B diet exemplify the two strategies adopted from this time on with high versus low nutrient concentration, tailoring the diet to the fish potential and environmental conditions of a specific farm. The development since 2004 has mainly focused digestibility of energy and nutrients in order to always guarantee an efficient blend independent of feed source. Later increase in NFE is mainly an effect of increasing use of plant ingredience. See text for more details concerning non marine feed ingredients in modern aquafeeds. NFE = Nitrogen Free Extract (mainly digestible and non digestible carbohydrates). Figure provided by Marie Hillestad, BioMar AS, Norway. Early data are based on the work of Erland Austreng, Akvaforsk AS, Norway.

11. Alanärä, A. 2000.
12. The graph is assimilated by Anders Alanärä at SLU, Sweden based on Ackefors, H. and Enell, M. 1994. *J. Appl. Ichthyol.* 10: 225–241. Naturvårdsverket. 1993. Jonsson, B. and Alanärä, A. 1998. Statistisk sentralbyrå. 2007.

stay soft also in cold water. The only consequence, known at present, is that the meat loses its healthy fatty acid profile as human food.

Twenty to thirty years ago, adult salmonids given a high protein and low energy diet (18 MJ gross energy) used an average of 2.5 kg of feed (≈ 10 percent water) (Wagbø *et al.* 2001) per kilogram of wet weight growth (≈ 70 percent water). Fifteen years ago, only 1.5 kg (Wagbø *et al.* 2001) of feed was needed to produce one kilogram of fish, while the figure today is 0.95–1.1 kg of low protein and high energy diet. As pointed out above the modern salmon diet contains more energy than it did twenty years ago (at present 20–23 MJ/kg, DW), and at the same time the protein fraction of the diet has been reduced from 50–60 percent to 35–45 percent DW (Figure 4). Farmers have thus achieved a significant improvement in efficiency, of close to 50 percent in energy and 70 percent on a protein basis, and thereby not only gained in economical terms, but also reduced emissions to the environment over the last 30 years. The early improvements (15–30 years ago) in feed conversion of intensive farming can mainly be ascribed to "educating the farmer", i.e. unnecessary pollution was caused by overfeeding. Today, feed accounts for such a large proportion of production costs that no farmer who wastes food can be profitable, and a number of various methods to register or recirculate uneaten feed are employed to minimise any waste. The more recent improvement (last decade) therefore represents advances in feed composition, feed production technology and domestication of the animal through selection programmes.

In fact, laboratory studies indicate even further scope for improvement in feed utilization. If the same salmon/trout/charr that need 0.95–1.1 kg of feed per kilogram growth is moved to a more protected environment, it only needs 0.8–0.9 kg on average, while some individuals will only need 0.5–0.6 kg (Kiessling *et al.* 1995, Grise-Helland and Helland 1998, Wagbø *et al.* 2001), i.e. in its extreme, less than half the average of today's practical situation, and less than 25 percent of the requirement 20 years ago. On an energy or protein basis, these findings indicate that close to 80 percent retention of protein and 70 percent of the energy is not only possible in theory, but also in the commercial system, provided that we can understand the factors causing the difference between the commercial and laboratory situation and use the right genetic material. When evaluating fish production, one needs to remember that, compared to other farmed animals, fish farming protocols and level of domestication are still very rudimentary and there is most likely room for significant improvements.

Reduction of the part of dietary protein used for energy in farmed fish has so far been achieved through improvement of the biological value of the protein (see also above). A good value implicates a protein with high digestibility and the correct amino acid profile for growth. This means, the better the biological value, the less protein has to be added to the diet, in order to support the same growth. In terrestrial farmed animals such a reduction of protein in the feed is compensated by an increase in carbohydrates, replacing the part of protein that would otherwise be used by the animal for energy. In fish, and in particular carnivorous fish, fat instead of carbohydrates has such "protein-saving" effect which is the underlying rational for the replacement of protein by fat in salmon diets shown in Figure 4. Carbohydrate, due to its low price and high availability on the global feed market, has even so repeatedly been tested in carnivorous fish diets with varying, but most often low success, this as dietary starch (the component of carbohydrates digestible to animals) has low digestibility in all fish and in particular in salmon. However, in most salmonides a 5 to 15-percent dietary inclusion (DW) of gelatinised (preheated) starch seems to have a small protein-saving effect and no negative influence on the uptake of other nutrients. Adding carbohydrates in salmonid diets is likely to reduce the need to convert glycogenic amino acids (protein) into glucose (carbohydrates) necessary to fuel the energy need of brain, kidney and blood cells. Hexokinase, the first rate-limiting enzyme in glucose metabolism, can be induced in all salmonids and omnivorous/herbivorous fish, indicating an optimum of 10 and 20–30 percent inclusion of digestible carbohydrates in the diet, respectively (Waagbø *et al.* 2001). In comparison, fat to a level of 30–40 percent of DW promotes growth and allows protein to be reduced to as little as 35–40 percent (DW, Figure 4) in salmon, depending on the life stage of the fish (small fish need higher level of protein).

Carbohydrates in aquafeeds, a comparison between different fish species

Even between the salmonids, but especially between omnivore/herbivore species, there are wide differences in carbohydrate tolerance. However, to get the proportions right, we call a fish herbivorous (plant eaters) if they can handle a carbohydrate inclusion up to 40 percent by weight, while a human or pig diet often contains 60–70 percent digestible carbohydrates (starch) by weight and 55–60 percent on energy basis. Rainbow trout is the salmonid that seems to have the best tolerance for carbohydrates, and their diets often contain 15–20 percent digestible carbohydrates, in addition to high levels of fat, allowing protein to be reduced to 30–35 percent of the diet. A level close to that seen in adult carp and tilapia (25–30 percent protein in the diet). However, in very intensive rainbow trout farming, protein is rarely lower than 35–40 percent (DW), i.e. fast growth demands a higher protein level. Most carp and tilapia diets contain levels of 30 or even 40 percent digestible carbohydrates by DW, and a general rule is that the higher the ability to digest carbohydrates, the lower the preference for lipids.

It has therefore often been argued that it is better to farm omnivorous/herbivorous fish like carp and tilapia from an environmental and global resource point of view as their feed contains less protein and marine oils and is higher in carbohydrate than that of carnivorous fish. However, this takes the argument out of its context, as a number of other factors, like energy (tilapia and carp need water temperatures from 25–32°C to be productive), transport, food safety, content of n3 HUFA (Table 1) and rural development need to be considered, if carnivorous cold water farming should be replaced by farming of tropical species.

Given the large differences between species in the ability to digest carbohydrates, the surprising fact is that no fish species seems to have any essential need for carbohydrates in the diet. All fish studied to date have the necessary capacity for endogenous glucose production based on glucogenic amino acids. That apparently no carbohydrates are needed, could be a reflection of the aquatic food web which, unlike the terrestrial one, is universally low in digestible carbohydrates and rich in protein, fat and minerals such as calcium and silicon. The main source of carbohydrates for most fish is the tissue glycogen of their prey, rarely surpassing one percent of wet weight, while algae and plant feeders may find high levels of starch in their natural diet. Some fish, such as tilapia (*Oreochromis* spp.) and silver carp (*Hypophthalmichthys molitrix*), which are normally considered to feed at a low trophic level, do in fact filter a mixture of plant and animal planktons that often is low in digestible carbohydrates. This lack of complex carbohydrates in the diet of fish, compared to farmed terrestrial animals, may be the underlying rationale for the absence of major microbial activity in their gut, but it is definitely the underlying rationale for the universally low ability of all major farmed fish species to metabolise as high levels of digestible carbohydrates as terrestrial animals. In fact, if most fish species, including tilapia and carp, are fed high levels of soluble and short-chain carbohydrates, like salmonids they will also be at risk of metabolic disorders that can provoke pathological liver changes and extreme obesity. Furthermore, juvenile fish of families such as tilapia and carp need a high level of highly digestible protein for energy and tissue formation, i.e. protein of animal origin. Chitin, the structural component of crustacean shell, is probably the second most common carbohydrate on this planet, second only to cellulose, and is often suggested as a possible carbohydrate source of fish. However, like cellulose, chitin seems to be indigestible without the enzymatic support of micro-organisms.

To conclude, the major difference in the ability to handle dietary carbohydrates between different types of fish seems to be confined to adult stages and differences found in the digestive tract. The major differences between different types of fish in terms of feed formulation are thus found at the level of refinement of the nutrient source, which is needed in order to make the nutrients accessible during digestion. Fish like tilapia and carp have a long digestive tract that is adapted to utilising protein and fat presented in combination with complex carbohydrates. In carnivorous fish with a shorter digestive tract, there is not enough time before the food reaches the end of the alimentary canal. Thus, high levels of complex/low digestible carbohydrates will reduce digestibility of the feed in fish with a short digestive tract (common carp, *Cyprinus carpio*, is an intermediate case between the carnivorous and omnivorous/herbivorous types).

It may therefore be a misconception that different fish have different requirements for protein to sustain growth. In fact, the differences could well be explained by differences in amount of protein utilised in energy metabolism, giving an appearance of differences in protein requirements. Such differences can be the result of evolving in a protein rich (carnivore) or protein poor (omnivore/herbivore) feed environment. Future research will show whether genetic selection, in combination with further development of feed sources and feed technology, will be able to further improve the ability to utilise non-protein nutrients in the energy metabolism of coldwater carnivore fish, reaching levels currently seen in that of omnivorous/herbivorous fish.

Plant and other feed sources as an alternative to fishmeal and fish oil in aquafeeds

The superior ability of omnivorous/herbivorous fish to "handle" low-density protein and fat extraction in the digestive tract, in spite of the presence of high levels of complex carbohydrates, has resulted in two feed manufacturing strategies. The low intensive strategy utilises low-grade local grains in a small-scale production. The mill is often simple and locally owned, and the feed is low in protein, rich in complex and poorly digestible carbohydrates and yields low growth rate in the fish. The high intensity strategy follows that seen in intensive fish farming of coldwater fish, using concentrated diets manufactured with advanced and expensive technology. The feed is often produced for a wider geographical area, and the mill is owned by a major corporation producing feed for several species of farmed fish. This type of feed is state-of-the-art, includes less non-digestible carbohydrates, is high in energy, and is used in more intensified production systems and yields high growth rates.[13]

Most plant protein sources need to be refined to reach the protein digestibility and density levels necessary for carnivorous fish diets, while the raw form of the plant source is often acceptable in the diet of omnivorous/herbivorous fish. Due to the market price of highly refined plant protein, these have not until recently, with increasing prices of fishmeal, been of interest as a feed ingredient for carnivorous fish. Soy, with its naturally high protein content, is an exception; it has been one of the favourite plant sources for salmon diets. However, a number of new technologies now allow economically viable refinement of several other plant sources such as peas, corn gluten, sunflower, lupines, etc.

However, both soy and most other plant sources contain a number of other substances that are produced by the plant, either as protection against grazing or as hormones. We call these substances "antinutrients", because they have marked physiological effects on the animal, often reducing feed utilisation. These effects are species-specific and counteractions in terms of processing methods and refinements will vary according to the fish being targeted. Salmon is especially sensitive to a number of substances in whole soy, causing everything from reduced protein and mineral digestion to severe inflammation of the hindgut, resulting in diarrhoea and possibly compromised welfare (Baeverfjord and Krogdahl 1996). The

13. S. Zimmerman, personal communication.

salmon feed industry has therefore reduced the use of soy, and is now directing its interest at other potential and less problematic plant sources. On the other hand, cod and especially the omnivore/herbivore warm water species seem to have a much higher tolerance for these substances, most likely as a result of being exposed to a more varied feed base through evolution. Replacement of fish meal with plant protein sources is today so efficient that a modern salmon diet yields close to more fish protein than goes into the diet (break even level is 25 percent fishmeal).

Most people find this 1:1 yield in marine protein acceptable, but the main criticism now focusses fish oil. Salmon is presently using more than 55 percent of globally available fish oil from wild fish resources (Figure 5) in spite that nearly 50 percent of the oil in salmon diet is of plant origin. On average seven percent (wet weight) of wild prey fish consists of lipids. However, one third

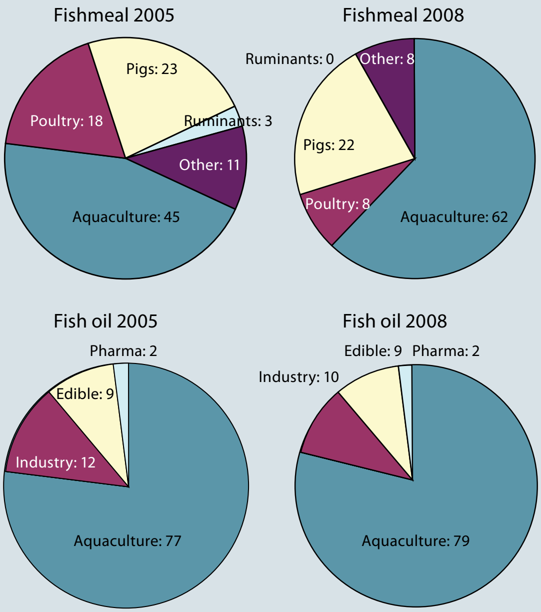

Figure 5. Changes in relative use of fishmeal and fish oil between commodity and animal species from 2005 to end 2008. Based on data from IFFO and FIN (Fishmeal Information Network) (2005 and 2009), Oil World (2009), and Tacon and Metian (2008).

Availability of marine fish oil has been a major bottleneck for increased salmon farming. Salmon feed demands 55 percent of globally produced fish oil (FAO 2009). However, Oil World (2009) predicts this to be reduced due to the practice of replacing nearly half of fish oil with plant oil in salmon diets. This may be the rational for the relative small change from 2005 to 2008, in spite an increase in global salmon production. Price of fish oil is at present mainly driven by the increase in direct human consumption (Oil world 2009). However, with technical progress human consumption may in the future be based on slaughter products from farmed fish rather than from wild fish oil (Oil world 2009). Pharmaceutical use is at present the only area with a profit margin for fish oil produced by micro algae.

Use of fishmeal, on the other hand, did already 2008 surpass growth predictions made for 2010, by the International Fishmeal and Fish Oil Organisation (IFFO) in 2005, with nearly 20 percent. This is likely an effect of an unexpected rapid increase in intensive tropical and marine aquaculture. Considering the present reduction in commercial catches of meal fish (IFFO 2009) predictions of future availability of fishmeal are presently ambiguous.

remains in the meal fraction, giving a yield of 4.5 percent pure oil. A salmon diet, if accepting a 1:1 yield (dry feed: wet weight fish), with a 38 percent fat and 25 percent fishmeal inclusion, demands on average 7.4 kg of wild fish for one kilogram of growth and 3.7 kg of wild fish if 50 percent plant oil replacement is used. Some would argue that this is an unfair comparison because in the 50 percent oil replacement scenario, more than half a kilogram of fish meal will be left over and may be used for producing e.g. fish with a low fat diet or even poultry. This is because each kilogram of prey fish yields 20 percent of its weight in fishmeal, compared to the 4.5 percent (after deducting the lipid in fishmeal) of oil (calculation based on personal communication; T. Åsgård, Nofima Marine).

Besides plants, many researchers advocate alternative marine sources like krill, by-catches or offal, as the ultimate way to supply dietary protein and lipids (marine type) to a steadily growing aquaculture industry (Shepherd *et al*. 2005, Tacon *et al*. 2006), but others have strong reservations, including both the realisation that human life ultimately depends on an environment in ecological balance and that maintaining such a balance sets limits on our use of biological resources, especially at higher trophic levels. Also most plant or animal-based sources suitable to fish are also suitable for human consumption. The interest in utilising these resources as human food may not be acute today, but no one doubts that a competitive situation for high-quality food resources will arise between humans and farmed animals in the future. The only sustainable alternative must therefore be scenarios in which the farmed animal becomes a net contributor, i.e. transforms "non-human" or "low-human interest" food resources into human ones in an ecologically sound way. A historic parallel is the grazing animal kept on "non-arable" land, where the animal, because of its rumen, is able to transfer complex carbohydrates, indigestible by the human stomach, into highly digestible protein, sugar and fat in the form of meat and milk.

Converting waste to food by fermentation

Micro-organisms are the most effective producers of organic material in nature, and often exceed 50 percent of dry weight in protein content, i.e. similar to meat/fish meal. Bacteria such as *E. coli* are capable of doubling their own biomass in as little as 20 minutes, given optimum conditions. Not only is a flora of different species from the main groups; bacteria, fungi/yeast and micro algae, capable of producing both protein and fat of the desired quality, but it will do so utilising carbon sources as diverse as human organic waste, CO_2, non-digestible carbohydrates such as cellulose, pentoses or even methane, to mention a few but important examples. It is not difficult to understand that micro-organisms are a prerequisite in a sustainable society, especially when one realises that many micro-organisms as a side-reaction can be "tricked" into reducing their main aim; that of producing new biomass (i.e. protein, fat and carbohydrates as building blocks for new micro-organisms), in favour of products such as biogas or ethanol, and to do so in compact bio-reactors under the complete control of man.

In order to obtain such high bio-production, very high levels of nucleotides are needed (DNA and RNA > 12 percent of DW are common), resulting in diseases, such as kidney stones and gout, if these organisms are eaten directly by man in large volumes. Farmed fish on the other hand has the metabolic capacity to utilise high levels of micro-organisms in their diet (see Skrede *et al*. 1998). Utilising micro-organisms would allow production of aquafeed together with such diverse commodities as waste treatment, bio-fuels and whisky production – to mention a few examples. In parity with plants, fish having been exposed to a variety of feed sources through evolution, seem to accept a wider range of micro-organisms in the feed more readily. Micro-organisms also contain a number of bio-active substances as well as a cell wall of varying digestibility. However, species and strains of micro-organisms have already been found that seem to be well suited as feed also to carnivorous fish. Therefore many believe that this is mainly a matter of matching the right organism or right process condition to the right fish species. The variety of micro-organisms is immense and even more importantly, they can easily be manipulated to change their metabolism and thereby their composition, by altered production conditions.

Refinement of low quality fish products

There is little or no prospect of increased volumes of fish meal in the foreseeable future. On the contrary; with more sustainable fishing practises, a recovery of large predator fish populations is expected and thereby an increased predation on prey fish (see Figure 5). The current growth of aquaculture, and the thereby increasing need for fishmeal and fish oil, has so far been based on an allocation to aquaculture from other farmed animals (Figure 5). Interestingly, this shift is signified by an increase in the quality of the meal itself. Traditionally, fish meal has been based on poorly treated raw material, often not even iced on the boat. This, in combination with high process temperatures, produced a protein of low biological value with high emissions of nitrogen during digestion. Such a low quality is accepted in terrestrial farmed animal feed, but not in fish feed. The introduction of high quality fishmeal with low bone content in aquafeeds during the late twentieth century resulted in a marked reduction in both nitrogen and phosphorus effluents per kilogram produced fish (Figure 3).

A positive side of fishing is that it removes biomass and thereby recovers nutrients from the water. Controlled fishing might also be instrumental in rectifying an artificial imbalance between predator and prey fish, in many cases caused by fisheries itself. The Baltic Sea is a prime example, suffering from eutrophication and an imbalanced ecosystem. However, fish in many waters, again with the Baltic Sea as a major example, is unfit for human consumption due to a high load of environmental contaminants. However, by modern cleaning procedure with active carbon, this biomass can be decontaminated and used in animal feed as fish meal instead of destructed. The contaminated fish will thereby be transformed back into high-quality food via fish farming. Other fish resources often mentioned are fish offal and by-catches/discards, either in the form of non-food species or catches too small to be commercially viable. Hydrolysation is one technique of great interest, in order to turn such by-catches profitable and to recover these nutrients via feed to farmed fish.

Mussels as animal feed

As in all animal production, feeding farmed fish with wild fish has been criticised from a resource point of view, because instead it should be used directly by humans. Ten percent of the food is normally considered to be retained from one trophic level to next (from prey to predator). As pointed out above, farmed fish are much more efficient than this, retaining well above 30 percent of the food in practice and 80 percent in theory. However, such high conversion rates are based on external energy inputs in the form of petroleum to catch/farm, concentrate, dry and transport feed and its ingredients. But the harvesting, processing and distribution of wild fish for food are also petroleum based. The high conversion efficiency of farmed fish has therefore been used as an argument that it is more efficient to catch feed/prey fish and feed them to farmed fish instead of leaving them in the ocean to be prey to a cascade of different predator fish. However, such arguments are difficult to support since the natural food web, quite apart from being petroleum-free, may have unknown positive spin-off effects. An alternative route is to use feed sources low in the natural marine food web. Wild blue mussel, a plankton feeder, was already twenty years ago tested as feed for farmed fish. However, the concept was at that time found to be unviable due to the high cost of de-shelling (Berge and Austreng 1989), as mussels otherwise had unacceptably high ash[14] content. Blue mussels are very effective plankton assimilators and from a human nutrition point of view, they have an excellent protein and fat (EPA and DHA) composition, even though their fat content is only a few percent of wet weight. By farming mussels for human consumption in eutrophic waters, an additional positive effect is achieved as nutrients are taken out of the water at harvest. Thereby farming functions as a trap for nutrients otherwise lost through leakage from other human activities as agriculture. Lindahl and Kollberg (2009) named this “Agro-Aqua recycling pathway”. In Sweden blue mussel farming is even accepted as an alternative to expansion of the nutrient purification steps at sewage plants.[15] Bivalve farming is also a major human nutrient net provider in tropical regions (FAO 2009).

A problem not often mentioned is that the ropes used to attract the free-floating mussel spat become overloaded during the growth cycle so that a number of small mussels fall to the bottom, creating local eutrophication that may have detrimental effects on the ecosystem directly beneath the farm. Some mussels are also still too small for the market at harvest and create an economic loss and disposal problem to the farmer. Both these “drop-off” and undersized mussels are po-

14. Ash is the remaining mineral content of organic tissue after combustion at 450°C for one hour.
15. The Lysekil experiment.

tential "waste", to be utilised as feed for farmed animals. The harvest waste of small mussels was recently tested as an alternative to fish meal for fish (Duinker *et al*. 2005) and ecological poultry production.[16] The fish study concluded that the cost in Norway of producing de-shelled mussel meal was not economically viable below a fish meal price of NOK 20/kg. However, a slightly better profit margin could be obtained if the remaining shell was sold as fertiliser. If used for laying hens, a better cost margin was obtained as they can use the shell for egg production and only partially de-shelled mussel meal could be used. On the other hand, the fish meal normally used for poultry is of lower quality and thus obtains a lower price than meal used for salmonid feed. A positive factor is that neither poultry nor salmonids seem to be sensitive to algae toxins that cause losses when blue mussels are farmed for human consumption, and thereby offers further possibilities for economising by providing an alternative market for mussels if their level of toxins is too high for the human consumer. Furthermore, blue mussels farmed in waters like the Baltic, high in xenobiotics, do not accumulate lipid soluble substances as dioxin and PCB, in contrast to fatty fish; partly due to low lipid content, partly due to low levels in the micro-organisms constituting their feed. Therefore they offer a possible route for recycling nitrogen and in part also phosphorus back into the human food system in contaminated waters like the Baltic.

Bivalve farming, allowing a quantifiable measure of nutrients removed from the water, has the potential to be included in an exchange system of effluent certificates, especially if the geographic distance between the effluent source and the mussel trap could be reduced (Lindahl and Kollberg 2009). At present the majority of bivalve farming is located in a marine environment while freshwater is dominant for fish farming. Neither freshwater mussels nor blue mussels grown in low salinity will reach a size suitable for the human food market. However, including the environmental gain, low salinity or even freshwater mussel production for animal feed may very well be profitable, especially if the meal is used to produce high-value ecological fish and poultry products (Goedkoop *et al*. 2007, Lindahl and Kollberg 2009).

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CONCLUSIONS AND WAYS FORWARD

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The various chapters in this book show clearly how most issues concerning fisheries, sustainability and development are closely interrelated and inter-dependent. In addition to this, they depend on and influence the environment and natural resources. *Fisheries* is based on fish (including shellfish), not only a natural resource of great value to man but also a key component of aquatic ecosystems. Fisheries managed in a sound way, adapted to the natural conditions and the environment, and in line with the ecosystem approach, contribute considerably to food provision, income, employment, recreation, etc. *Sustainability* – both ecological and socio-economic – is a precondition for human well-being in the long run and a goal for most sectors in society. *Development* is the key to a better life, particularly for the countless multitudes of poor people in developing countries, but also for a majority in the rest of the world. Its links to fisheries and sustainability are obvious.

The global interrelations are complex. Both inter-sectoral and geographical links are common. For example, fish consumption in Sweden impacts fish stocks, aquatic environments and socio-economic conditions in other countries all over the world. Trade in fish products, purchase and exchange of fishing rights, illegal fishing in foreign waters, global change, transboundary environmental degradation, invasive alien species and development aid are examples of such links.

As noted in the book, the lack of a holistic view of these issues is a major factor underlying the shortcomings and problems that considerably affect the food supply, natural environment and overall basis for life, including the development potential, for a vast number of people in developing countries. These shortcomings and problems also influence the developed countries in various ways and thus – directly and indirectly – affect us that belong to the privileged part of mankind. Thus, an obvious starting point for a discussion of these issues is how a holistic view of them can be achieved.

The international community has agreed at state and government levels on a number of key resolutions that offer objectives and guidelines for future development as well as political undertakings to promote their fulfilment, e.g. the UN Millennium Development Goals. These objectives and guidelines are of major importance as lodestars for development at all levels (global, regional, national and local) and in all parts of the world, even if there is a certain focus on developing countries. Their key messages may be summarized in the concept of sustainable development. It is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Both ecological and socio-economic progress is included. Sustainable development has been in focus of most development activities during the last two decades, at least in theory. The general nature of the concept has unfortunately made its actual content the subject of various interpretations and adaptations to selfish interests.

The discussions and conclusions in this chapter proceed from the concept of sustainability as a development goal. The original interpretation of the concept, as defined by the UN Global Conference on Environment and Development in 1992, has been applied. We attempt to summarize and analyze the various sections primarily from the sustainability perspective and highlight aspects that we feel should be underscored for various reasons.

Ecological sustainability is an imperative necessity for fisheries. Unlike other kinds of biological production (e.g. agriculture and forestry), capture fisheries utilize the yield of more or less natural ecosystems. That means that a sustained production capacity of these ecosystems is a precondition for sustained fisheries which, in its turn, means that conservation of aquatic environments is a high priority concern for the fisheries sector. Environmental degradation affects fisheries more than most other sectors.

The chapters in this book are by authors with different backgrounds, focuses, starting points and perspectives. Problem formulations, analyses and conclusions vary. Overlaps occur. Broad overviews alternate with exemplifying discussions of specific issues. This arrangement was chosen in view of the subject's considerable range, complexity and controversial character. The scientific knowledge base is weak in some respects. A variety of opinions on a number of issues are dealt with in the book. Apart from providing a forum for these viewpoints, the goal has been to ensure that the combined inputs cover the most important points of the subject. However, for practical reasons, certain aspects have been handled in a more general manner than others. The book is divided into four parts which are discussed separately here.

Part One: Water, fish and fisheries

The first part of the book presents basic prerequisites, from a natural science perspective, for fish and fisheries all over the world. Both marine and inland waters are covered. Global overviews are then given of environmental degradation, climate change and other factors which affect fisheries. Also environmental impacts of fisheries are covered. Different types of fisheries, marine and inland, in different parts of the world are described. Fishing activities, stock situations, socio-economic importance etc. are dealt with.

Global overviews of oceanographic conditions and Large Marine Ecosystems (LMEs) set much of the scene for the description of marine fisheries in the book. Nutrient supply and nutrient recirculation set the limits for primary production which is the basis for fish and shellfish production. Strikingly, shelf areas including upwelling areas along the eastern side of the Atlantic and Pacific Oceans, which cover only about 10 percent of the sea, yield more than 80 percent of all marine catches. However, it is underlined that fisheries management regimes also play an important role and to a large extent have affected fish production negatively.

It is strongly emphasized that marine environments all over the world show serious negative impact caused by man. Their ability to provide ecosystem services of value to mankind – e.g. fisheries – is decreasing. In many marine areas the cumulative and cascading impacts of various human activities have caused dramatic changes in ecosystem structures and functions. The problems are substantial in industrialized countries – despite environmental laws, administrations, etc. – and increasing in developing countries. Pollutants causing chemical contamination constitute major problems which may directly affect fisheries. For example, eutrophication causes profound negative ecological changes. Toxic long-lived substances, such as dioxine, accumulate in the food chain and hit top predators – including man – especially hard. Pollution is a problem of global concern but often shows specific severity in coastal waters in developed countries.

Habitat degradation is another serious problem, not least affecting coastal habitats in developing countries, as pointed out by several authors. Fisheries are badly affected, especially because the reproduction of many fish species is impaired. Well-known examples are siltation of coral reefs and sea grass beds, exploitation of mangroves and drainage of wetlands. Habitat degradation is also caused by fishing itself, e.g. bottom-trawling – especially on rocky habitats – and dynamite fishing. An issue of great concern is trawling on seamounts and similar habitats in high seas with unique and diverse ecosystems extremely sensitive to physical damage and overfishing. Such devastating fishing operations – comparable to mining – have been carried out at an increasing scale during the last 10–20 years. The deleterious effects on biodiversity, including sustained fisheries, are far-reaching. It is noteworthy and regrettable that the international community has not yet managed to stop or at least regulate these excesses. By-catches of seabirds and marine mammals constitute another environmental problem caused by fisheries. The magnitude varies but is frequently significant. Intensified measures to reduce the problem are urgently needed in many areas.

Ecological and environmental consequences of overfishing are described and discussed by several authors. The unanimous general opinion seems to be that overfishing causes serious problems, even if somewhat diverging views on the magnitude of the problems and the prospects to overcome them in the future are expressed. However, it is a fact that many fish stocks all over the world are managed in a non-sustainable manner, mainly due to bad governance. It seems to be evident that the recent, massive biomass declines in various LMEs essentially are due to overfishing. Trawling shows a general tendency to overexploit fish stocks.

Large predators are usually first affected by overfishing and their depletion causes ecosystem changes which may be far-reaching and difficult to reverse. The expression “fishing down the food web” is a reality. It is evidently the most common underlying factor behind the declines of the mean trophic level in fish catches, a fact which has been observed all over the world. In addition, cascading effects throughout the entire ecosystem may occur.

In a pessimistic – but plausible and well substantiated – contribution, the global development of fisheries is described as a continuous expansion. It started in industrialized countries over a century ago, extended gradually all over the world and is now being completed by industrial fleets operating in the southern oceans. One factor behind this development seems to be an extensive occurrence of illegal, unreported and unregulated (IUU) fishing, especially in high seas and the economic zones of developing countries. Fisheries have also spread from a few targeted species to a situation where all palatable species are targeted. Major consumer countries, e.g. the EU, have been able to compensate decreasing catches in their own waters by increasing imports. It is anticipated that the development, if it continues, in the next decades will lead to extensive stock collapses and even to a succession of local extermination, followed probably by global extinction of a number of large marine fish species. These predictions – or at least fears – are important, both from a scientific and a management perspective. The situation is definitely so serious that the precautionary approach should be immediately applied.

There are, however, also successful rehabilitations of deteriorated fisheries described in the book. It seems as if collapsed stocks under certain conditions can recover, provided that strict management regimes are applied. For example, gradually more successful management regimes have been applied in Norway, Iceland, USA, Australia and New Zealand, while the EU has been less successful. The best way quickly to improve the present distressing situation is probably to establish a sufficient number of large marine reserves where marine ecosystems and their species can rebuild some of their past abundance.

The key to sustainable fisheries is good governance. To bring that about, the basic problems have to be addressed, particularly the frequent mismatch between the production capacity of the resource, the fishing capacity and the demand for fish. Open access to insufficiently regulated fisheries should be replaced by well managed fisheries with efficient regulation of access, fishing effort etc.

A rather new threat to fisheries, which most authors deal with, is climate change. Evidently it will affect aquatic environments globally – and thereby fisheries. Various consequences, beyond the basic increase of temperature, and ways to reduce their impacts on fisheries, are discussed in the book. One potential problem for marine environments in general, which is associated with climate change, is the acidification of the oceans due to increased absorption of carbon dioxide from the air. The consequences for coral reefs, organisms with calcareous shells, etc., may be severe and fisheries may also become badly affected.

The introduction of the concept of LMEs as a basis for regional management of coastal waters around the globe was an important step forward in the efforts to build up an international framework for such management. The presentation of global warming broken down to the 64 LMEs underlines this. Their size and delimitation makes it possible to assess temperature trends in relation to fisheries biomass yields and is suitable for the application of the ecosystem approach. Data from the last 25 years show that there is a consistent warming of LMEs, with the exception of two upwelling areas. Fast warming LMEs are found primarily at higher latitudes and slow warming LMEs primarily, but far from exclusively, at lower latitudes. Fisheries biomass yield is increasing in a number of fast warming LMEs, for example in the northern parts of the Atlantic, but decreasing in others. It is increasing in a majority of the slow warming LMEs. The importance of management regimes for fisheries biomass yield is evident also in this case.

The impacts of climate change on fisheries biomass yields in LMEs seem to differ a bit between various areas and show no clear trend. This is of great interest, but it should be noted that the differences are based on a relatively short time period and are affected also by fisheries. The consequences of climate change seem to be aggravated in coastal waters closer to the shore, particularly in developing countries. At the local level in such countries, climate change is a real threat, particularly to small-scale fisheries. In many coastal areas a combination of climate-related stresses and widespread overexploitation of fisheries reduces the scope for adaptation and increases risk of stock collapse. It is evident that healthy ecosystems (intact coastal habitats like coral reefs and mangroves, large and diverse fish stocks, etc.) increase resilience and capacity to withstand consequences of climate change in coastal areas.

Capture fisheries are extremely diversified. Most catch figures are rough estimates which in many cases are marred by errors. Various estimations and official figures are presented in the book. According to a probable estimation, total global marine catches – including discards and IUU-fisheries – peaked around 120 million tons per year about 25 years ago, and subsequently decreased somewhat. The magnitude of this catch figure indicates the immense importance of marine fisheries, emphasized by several authors, through provision of nutritious food, generation of employment and income, generation of taxes and export revenues, enabling recreation, etc. The fisheries sector includes about 40 million professional fishermen and four million vessels. The estimated first-hand value of the global capture (marine and freshwater) fisheries is about USD 85 billion.

Freshwater as a basis for fisheries is dealt with from different angles. A common conclusion is that freshwater resources and habitats are under severe pressure, which constitutes a serious threat to freshwater fish and fisheries, particularly in developing countries. Therefore, the most urgent measure to keep and develop thriving freshwater fisheries seems in many parts of the world to be environmental conservation focusing on freshwater and habitats linked to it. Freshwater bodies, such as lakes, rivers and wetlands, are increasingly affected by changed hydrological regimes (e.g. increased flow variations, damming up, blocking of flow, drainage and water removal), as well as pollution, siltation and the like. A major factor behind the pressure on freshwater is agricultural development (leading to intensification, irrigation, deforestation, land clearing, erosion, use of chemicals, etc.). Another factor is hydropower development with the construction of dams and changed water regimes. The need for conservation of freshwater and freshwater ecosystems, including fish, is often neglected in planning for the development of agriculture and hydropower. There is an urgent need for a holistic management of freshwater resources, based on the ecosystem approach to the management of watersheds, where fisheries and aquaculture are given due consideration. This approach should consider not only water quantity and quality but also connectivity of river systems, biodiversity conservation etc.

Alien species constitute a general threat to aquatic biodiversity which is highlighted in the book. It is of specific significance to freshwater fisheries. There is an urgent need for increased consideration of that problem in the management of such fisheries.

Climate change constitutes a further pressure on freshwater fisheries. For example, freshwater availability is projected to decline, most significantly in southern and northern Africa and a number of other hot spots. This is an obvious and serious threat to fisheries. The impact of climate change on the small-scale fisheries of inland waters is of great concern. The majority of the world's millions of freshwater fisherfolk live in areas that are highly exposed to climate change. Climate change threatens the multiple benefits of fisheries, notably the contribution to poverty reduction. It decreases biodiversity and production, affects human health and damages physical assets.

Also inland fisheries are affected by overfishing. Its consequences are similar to those recorded in marine waters. Fishing down the food web has occurred in many places. Overfishing has contributed to collapse of stocks and even extinction of fish species.

The importance of freshwater fisheries to man is strongly underlined in the book. According to official estimates, freshwater catches are about 10 million tonnes per year and are still increasing, especially in developing countries. On the contrary, most industrialized countries show decreasing catches. There is a potential for further increase in production in many areas, provided that the environment is not further degraded and sustainable management regimes are applied. Inland fisheries are an important source of income for 50–100 million people and of animal protein for still more.

One category of fisheries, which is often more or less neglected when the importance and the benefits of the sector are discussed – especially compared to commercial and subsistence fisheries – is recreational fisheries. Its great importance from both economic and social perspectives is strongly underlined in the book. In many parts of the world, particularly in fresh and coastal waters in industrialized countries, recreational fishing is becoming the most important beneficiary of fish stocks. About a tenth of the population across all industrialized countries engages regularly in recreational fishing. It provides much social, economic and ecological benefit to society; especially its role as a major economic driver should be emphasized. In many rural areas, recreational fishing is an important part of the tourist industry. For many fish stocks, e.g. the Atlantic salmon in the Baltic Sea, the economic revenue per catch unit of recreational fishing is much higher than that of commercial fishing. Recreational and commercial fisheries are usually carried out side by side. Conflicts do occur but are usually negligible or of minor importance, and can be avoided or reduced by proper planning. Finally, it should be emphasized that recreational fishing, generally speaking, exerts less pressure on fish stocks and causes less environmental damage than commercial fishing. Furthermore, within the context of recreational fishing a lot of voluntary work is devoted to restoration and conservation of fish stocks and habitats.

Part Two: The science and politics of fisheries management

The second part of the book presents different aspects on governance and fisheries management: legal, scientific, socio-economic etc., both in developed and developing countries. Focus is on conditions for sustainable fisheries. Management strategies and instruments, problems and failures, case studies etc. are discussed from different perspectives. It is underlined by all authors that good governance is the basis for fisheries management regimes aiming at sustainability. Such governance must include appropriate legislation, efficient management structures, qualified scientific advice, pronounced political will, etc. Shortages regarding only one of these components may be sufficient to jeopardize the sustainability of fisheries management. In practice, however, political will seems to be the individual factor which most frequently is the key to management failures. Successful fisheries management should:

- adopt a long-term perspective aiming at sustainability,
- be based on sound scientific advice,
- apply the ecosystem and precautionary approaches, and
- consider – and bring about a reasonable balance between – all relevant aspects and interests (also outside the fisheries sector itself, e.g. impacts of fisheries on socio-economic conditions and biodiversity).

Qualified scientific advice is a prerequisite for successful fisheries management based on biological conditions and aiming at sustainability.

However, as underlined by several authors, such advice does not automatically lead to management success. Actually, most management failures are not due to the lack of qualified scientific advice, but to the lack of will to follow the advice given. One well-known example is fisheries in EU waters in the north-eastern Atlantic whose management has not been successful – despite access to excellent scientific advice and management capacity to make use of that advice.

The important role of scientific advice is discussed thoroughly in the book. The work of ICES – the international scientific body for the north-eastern Atlantic – is the starting point. Fisheries management advice should be right, relevant, responsive and respected. The first three can easily be addressed within the scientific community itself. The fourth issue – getting the advice accepted – is more difficult to address and probably presupposes involvement of fishers and other stakeholders in the scientific advisory process. How to effect this is a real challenge for science in fisheries management.

The ecosystem and precautionary approaches are two cornerstones of sustainable fisheries management. They are partly linked to each other and are being applied to an increasing extent. However, there is still an urgent need for a more frequent, systematic and strict application of both approaches, at national and international levels. The ecosystem approach to fisheries is discussed in detail in the book. The importance of the concept, as a management tool, and its wide application are underlined. It should be specifically emphasized that the approach stands for both the sustainable yield of aquatic ecosystems and for their integrity, species stock etc. Up to now, the important biodiversity conservation aspect has not always been fully considered in the application of the ecosystem approach to fisheries management.

A joint Swedish/FAO-initiative in the 1990s laid the foundation for the application of the precautionary approach to fisheries management. The concept has then successively been specified and made more operative. It should not only focus on maintaining the reproductive capacity of specific stocks, as is often the case in fisheries applications, but also address impacts on the whole ecosystem which is affected by fishing activities. Four basic foundations for the precautionary approach are:

- All fishing activities have environmental impacts which should not be neglected until it is proven – from a sustainability perspective – that it is appropriate to do so.
- Cessation of fishing activities with potential serious adverse impact may be required. However, it does not imply a total fishing moratorium until potential effects have been assessed and found to be negligible.
- All fishing activities should be subject to prior review and authorization and carried out in accordance with a concrete, all-embracing management plan.
- The standard of proof used at authorization of fishing activities should be commensurable with the potential risk. The expected benefits of the activities should also be considered in the authorization process.

This book gives a comprehensive overview of the legal framework for fisheries management at the international level. It consists primarily of two global agreements – UNCLOS and UNFSA[1] – and a number of regional agreements. An important conclusion is that much more could be done – based on the existing legal framework – to bring about sustainable fisheries management at the international level than is done today. There is a need for improved legislation in some respects, but the main reasons behind the present unsatisfactory – but slowly improving – governance situation are insufficient capacity (particularly in developing countries) and lack of political will, not deficiencies in the legal framework.

Management problems include insufficient and uncertain scientific advice, insufficient regulation, faulty compliance, IUU[2] fishing, etc. According to international law, countries are obligated to cooperate in the field of fisheries management. In most cases, however, such cooperation does not comprise all concerned countries. Of particular concern is that flag of convenience is a common phenomenon and that many states do not take the required responsibility for vessels flying their flag.

The problem of IUU fishing is specifically dealt with in the book. Its magnitude is underlined, but it is also shown that the problem is tackled by the international community, especially within the FAO. Slow progress is made but a lot remains to be done. For example, IUU fishing is a major factor behind the degradation of unique and valuable bottom habitats in high seas through trawling. Many vessels involved in these activities are owned by companies in the EU and other industrialized parts of the world but fly flags of convenience.

It is often stated that fisheries management can be made more efficient by involving local fishers in management decisions, both in developed and developing countries. This is certainly generally true, but the statement needs to be shaded off a bit. For example, it is evident that in many industrialized countries – including Sweden – a strong political influence of the commercial fisheries sector has been an important factor behind the failure of the public fisheries policy as regards stock conservation and sustainability. The fisheries lobby is much stronger than – for example – the environmental lobby and does not always seem to think of its own good in the long run.

African experiences, both positive and negative, of fisheries co-management programmes are described in the book. Successful cases are characterized by, inter alia, enabling policies and legal frameworks, effective institutions, real participation by fishers and other stakeholders and incentives for individuals to participate. In many cases, however, co-management programmes failed to improve governance and were detrimental to the local fisherfolk. It is evident that co-management alone is not a general solution to management problems.

Part Three: Aquaculture and seafood

The contribution of aquaculture to food for humans is substantial. At present this corresponds to nearly 50 percent of fish and shellfish con-

1. United Nations' Convention on the Law of the Sea, and Fish Stocks Agreement.
2. Illegal, unregulated and unreported.

sumed by man. Fish is mainly produced in freshwater, and shellfish in marine areas. The aquaculture sector still maintains a high annual rate of increase. Asia continues totally to dominate aquaculture production with about 90 percent of global weight and 75 percent of value. China dominates the Asian production to a similar extent. Only two countries outside Asia – Chile and Norway – belong to the top-ten producers of the world. The dominating species produced are carps and molluscs, and in the second place crustaceans, mainly shrimps, and salmonids.

Feed is often the key factor in aquaculture. It represents the largest cost for farmers and is the key to further development. Fish species in temperate waters are mainly carnivorous, like salmonids, and obtain nearly 100 percent of their energy from external sources (intensive fish farming systems). Fish species in tropical waters are usually omnivores or herbivores, e.g. tilapia and carps, which are not given fabricated feed (polyculture or extensive systems). There is a plethora of various aquaculture systems on land (mainly ponds), as well as net pens in freshwater and marine waters. Of great interest are integrated systems where grazing animals on land fertilize ponds with their faeces. Most fish cultivated in net pens are raised in lakes and coastal sea areas, but also in off-shore production in large net pens or other devices. On land, closed recirculating systems or other systems supplied with warm water are increasingly used in temperate areas and evidently offer potentials for further development. In such systems, pollutants can be collected to prevent eutrophication of the recipient.

Feeding technology has made great progress; pelleted feed leads to less waste and substantial gains in the production process. Compared to terrestrial animals, the retention of the protein content of the feed is much higher. From an environmental point of view, water pollution is a disadvantage of fish farming compared to the production of terrestrial animals, because it is more difficult to prevent eutrophication from fish farms, especially pens. However, great progress has been made to reduce the environmental impact by better technology and above all better feed. The amount of released nitrogen and phosphorus, per kg produced fish, to the environment has decreased substantially. 20–30 years ago, adult salmon was given a high-protein and low-energy diet; about 2.5 kg feed was needed to produce 1 kg of fish. Today the about 1 kg of low-protein, high-energy diet is sufficient.

With increasing prices of fish meal, there is an incentive partly to replace fish protein with plant protein. More importantly, this is desirable from a natural resources perspective. However, there are drawbacks with plant protein; the so-called "anti-nutrient substances" must be processed in various ways before they are added to the feed. Replacing fishmeal with plant protein has nevertheless become so efficient in modern salmon diets, that 25–50 percent of the fishmeal now consists of plant protein. At present, focus is on the use of fish oil, since aquaculture uses 4/5 of the total world production, although 50 percent of the oil in, for example, salmon feed is of plant origin.

Measures to reduce emissions from fish

farms, in combination with increased efforts to find suitable locations, have a great potential to reduce conflicts between fish farming and other interests. Important tools to this end are physical planning and environmental impact assessment.

Seafood contains a number of valuable components from a nutritional point of view, which make them potential members of the so-called functional food family. Increasing awareness of this remarkable quality will certainly affect future demand for fish. Seafood is a good source of valuable proteins, omega-3 and other important fatty acids, vitamins and minerals.

Unfortunately, potential risks also have to be taken into consideration, first of all due to environmental pollutants, e.g. chlorinated hydrocarbons and methyl mercury, which accumulate in the food chain and may reach unwholesomely high levels in fish meat. Greater attention should be paid to this problem, both in environmental and fisheries management. Certification and increased traceability are also measures which could improve the situation. Other problems, which also affect fish consumption negatively, are the occurrence of toxins in mussels emanating from toxic phytoplanktons and allergic reactions provoked by naturally occurring proteins in fish and shellfish.

More than a billion people on earth are, more or less, dependent on seafood as the main source of animal protein. Globally, about 12 percent of the human consumption of animal protein consists of fish – or 16 percent if China is included. Seafood consumption is highest in Asian countries, with Japan in the lead, but the consumption is also high in countries like Korea and Malaysia. Statistics are uncertain, as clearly shown in the book, but it is evident that fish protein is of specific importance to national food supply – and public health – in many developing countries. This fact should be better reflected in development policies.

Part Four: Fisheries, trade, development and poverty reduction

Fisheries and aquaculture contribute to meeting the Millennium Development Goals through employment, provision of nutritious food, generation of revenues for local and national government from licenses and taxation on landings, from export revenues, and from various upstream and downstream multipliers. For example, fisheries and aquaculture employ over 50 million people worldwide – a quarter of them in aquaculture – 98 percent of whom are from developing countries. In a global export business worth nearly USD 80 billion annually, African export earnings from fishery products and services are calculated to be over USD 2.7 billion per year, and fisheries sectors in countries such as Namibia, Uganda, Ghana and Senegal contribute over 6 percent to their national GDPs.

Despite the significant contributions that fisheries and aquaculture make to employment, nutrition, and trade in the developing world, they are rarely included in national development policy and donor priorities. Part four of this book shows that this lack of attention to the sector is particularly problematic given that capture fisheries are currently being utilized at capacity and that further increases in production will have to come from expansion of aquaculture.

The contribution of fisheries and aquaculture to development has consistently been underestimated, as several authors point out. The Sustainable Fisheries Livelihoods Programme of the FAO developed methods to reassess the contribution of fisheries to development in Africa. It also managed to raise awareness in some targeted countries. However, it is difficult to valuate small-scale fisheries, and policy makers often do not have access to data which reflect the importance of fisheries and aquaculture to development. Knowledge of artisanal, subsistence and inland production, fish-based livelihoods and consumption patterns in developing countries tend to be very poor.

Employment in fishing and aquaculture has grown rapidly over the past few decades – from 13 million people in 1970 to over 41 million in 2004 – and at a higher pace than both world population and employment in agriculture. Authors emphasise the particular importance of the sector for women: millions of women in developing countries are employed in fisheries and aquaculture, participating at all stages in both commercial and artisanal fisheries, though most heavily in fish processing and marketing. The post-harvest sector is an important source of employment for the poor, with an estimated three people for every fisher. One author reminds us that fish landing sites – often centres of the cash economy in otherwise remote areas – stimulate the kind of monetisation of the rural economy that is seen by development policy makers as the means to reduce rural poverty. In small island states and fishery dependent regions of larger economies, this sector is a significant contributor to the overall economy and society.

The post-harvest sector therefore provides an opportunity for both enhancing the livelihoods of the rural poor and meeting ever-increasing food needs. However, post-harvest losses reduce revenues of fishers and traders and the overall food fish supply. One author explains this with a lack of adequate infrastructure, inadequate preservation technologies, and poor market access. In some countries in sub-Saharan Africa, an average of 30 percent of the landings is lost. Strikingly enough, the remedies suggested are "low-tech": improved processing technologies such as screens against insects, improved 'chorkor' smoking kilns, and mesh trays to elevate the fish off the ground. This could reduce losses significantly, and give both greater food security and increase incomes for processors and traders.

In sub-Saharan Africa per capita fish supply is declining, due to rapid population growth, a stagnant capture fishery production, and the slow expansion of aquaculture in the region. Even when consumed in small quantities, however, fish often is a nutritionally important part of people's diets in developing countries. This is emphasised several times in this and the previous part of this book: it is a vital source of protein and micronutrients, and improves the quality of protein in largely vegetable and starch-based diets by providing essential amino acids. It is particularly important in the diets of the poor, as the most affordable form of animal protein: "Rich food for poor people".

An expansion of aquaculture production in sub-Saharan Africa is stressed by several authors as a means to allow the region better to meet its rapidly increasing demand for fish. Though the obstacles are manifold, it is however pointed out that aquaculture is often easier to manage than capture fisheries. Access to water is a key issue, causing problems for landless wishing to farm fish in cages, for farmers wishing to abstract additional water for fish and for downstream users where large numbers of farmers wish to harvest rainwater for pond culture. Encouraging multiple uses of water, however, can increase its productivity and allow for simultaneous development of several sectors. Often cumulative effects are not taken into account, in association with other sectors such as agriculture, industrial development, tourism or hydropower. An ecosystem approach to aquaculture (EAA) could provide a more holistic water management.

Over 30 percent of the fishery commodity production in developing countries is exported, and it is an important source of foreign exchange for many countries, including Chile, Mozambique, Senegal, and Thailand. According to one chapter international trade in fisheries products has been shown to have a positive effect on food security in many developing countries, stimulating increased production, and generating foreign exchange which can be used for food imports. One author emphasises that production for export can help to raise the incomes of poor fisherfolk and people employed in fish processing, enabling them to achieve greater food security through enhanced purchasing power. In contrast, another contribution states that, exports may deprive a section of the domestic consumers of a variety of fish, leading to a potential loss of food security for them. Fish import for human consumption can help to stabilise or reduce fish prices for poorer fish consumers. However, this can have an adverse effect on the income of fishers in the importing country by lowering their food security.

Yet other authors draw the conclusion that trade per se is neither positive nor negative for the environment or natural resources, but that trade acts as an amplifying factor. The theoretical work reviewed in one chapter confirms that both critiques and proponents of free trade with renewable resources have some valid points. Trade may be harmful to stock conservation and may even lead to welfare losses; on the other hand trade does generate benefits, and may sometimes also lead to improvements in stock conservation. While trade generally is beneficial for growth and welfare, according to one chapter, the combination of pure open access and trade liberalisation may both reduce welfare and stocks for a country. This can be reinforced by 'bad' subsidies – support to the industry that contributes to increasing fishing pressure. However, according to these authors trade liberalization may have the positive effect of promoting property rights in response to increased fish exploitation. This means that if the underlying structures are defective or weak – that for example subsidies make it more profitable to fish – trade will amplify the effects, with the potential of negative results for the environment, food supply and livelihoods.

Therefore, sustainable resource management is a necessary condition for sustainable international trade. The WTO can play a role by adopting rules to help eliminate bad subsidies, such as public support for vessel construction, fuel subsidies, or fishing rights outside developing coastal countries provided at limited or zero cost. This can emphasise good subsidies, such as to improved fisheries management or monitoring and enforcement. Weak resource management corresponds to an export subsidy on producers, which according to this chapter could be met by countervailing duties under trade law according to present rules.

The main obstacles to increased export from developing countries, says one author, are stringent and increasing requirements for food safety, animal health, environmental and social standards. On the other hand, in view of the high global demand for fish, and the limited assets available, losses and illness caused by spoilt seafood, are sufficient reasons to take measures to improve quality and safety, as one chapter points out. International harmonisation of rules is urgently needed, since this would reduce the need for special national rules.

To conclude, it is difficult to understand the low priority of fisheries and aquaculture in national efforts to reduce poverty and in international development cooperation, given their substantially beneficial role for economies, food security, health and livelihoods – and the potential to contribute even more. However, even if donors do not care much for fisheries and aquaculture, they could hardly disregard the need for sustainable management of natural resources, living and other, aquatic and terrestrial – and for good governance in general. Overfishing, poor or non-existent fisheries management and control, fisheries access agreements, ad hoc licensing of foreign fleets, as well as poaching – often a form of international organised crime at a large scale – are all disastrous to the natural resources and a consequence of poor government structures in general. Many of these factors, not least foreign fisheries both legal and illegal, also directly contribute to aggravating bad governance in many poor countries. How can policy makers and donors still turn a blind eye?

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This 'Academy Blue Book' describes global fisheries and aquaculture from the points of view of sustainable ecosystems, economy, trade and development. The main objective is to provide an overview of fisheries and aquaculture, their natural conditions and their significance for economic development and people's livelihoods. A further objective is to show the impact of rich countries on the developing world within this sector through trade, aid and global fisheries.

The target group is broad in scope: policy makers, general public, students. The Royal Swedish Academy of Agriculture and Forestry wishes to take part in an ongoing discussion, sometimes bordering to a public row, with a scientifically based and easily accessible book. This book should be seen as a source of information intended to raise the level of knowledge in general.

Threats and possibilities in fisheries and aquaculture are brought forward in the contributions from fifty-two authors from academia, international organisations and public administrations. It is striking that few countries, rich or poor, have succeeded in creating a comprehensive management system for marine and freshwater resources. Fisheries are not only important to a great many people as a source of food and livelihoods, fisheries cause ecological and socio-economic problems that are detrimental not only to people that depend on fisheries, but to biodiversity and the ecosystem as a whole. In this respect, it is essential to make the right connections between the ecological impact and poverty reduction.

Fisheries and aquaculture are essential to the economies, trade revenues and food supply of a large number of developing countries, but are generally ignored in development and trade policies. However, rich countries still influence fisheries and aquaculture and the contribution to development in many ways. Neither in natural resource management, nor in development co-operation, are fisheries and aquaculture treated in their proper context.

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