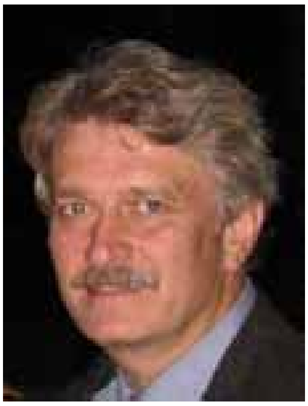
Session 5: Progress – the future

James L. Anderson



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Aquaculture and fisheries: complement or competition

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ABSTRACT

The growth of the aquaculture sector has both positive and negative impacts on the traditional fisheries sector. In the ecosystem some aquaculture has: a) directly influenced fish stocks through its use of wild fish stocks for inputs such as feed; b) influenced fish stocks through intentional releases (salmon stock enhancement) or through unintentional escapes; c) displaced wild fish through its use of habitat and, in some cases, enhanced fisheries habitat (e.g. some oyster operations); and d) influenced both wild and farmed fish stocks through disease transmission and related interactions. However, aquaculture also has a tremendous influence on wild fisheries through international trade and the market. It has: a) influenced prices negatively through increased supply and positively through the development of new markets (e.g. catfish); b) changed consumer behaviour, c) accelerated globalization (e.g. salmon, shrimp and tilapia); d) increased concentration and vertical integration in the seafood sector; e) resulted in the introduction of new product forms; and f) significantly changed the way seafood providers conduct business. The growth of aquaculture has stimulated the traditional wild fisheries sector to improve quality and, in some cases, attempt to become more efficient. Growth in aquaculture has created a backlash of criticism from the wild fisheries sector (and environmental groups) through the media and, in several cases, has been met with increasingly restrictive international trade barriers (e.g. salmon, shrimp and catfish). These interactions and changes are explored and implications for the future of the wild and farmed seafood sectors are discussed.

INTRODUCTION

The growth of the aquaculture sector has both positive and negative impacts on the traditional fisheries sector. There has been considerable discussion regarding whether aquaculture and fisheries are competitive or complementary. The objective of this paper is to address this issue and its implications for the future of the seafood sector. First, is competition positive or negative? Are complements negative or positive?

Competition can be positive if it results in improved efficiency and/or increases in innovation. However, it may be considered negative if it results in bankruptcy and displaces the existing industry, community and heritage. A complementary activity may be considered positive if it expands demand or revitalizes growth. However, a complement can be considered negative if it enables inefficiency or stifles innovation. Whether something is negative or positive depends on one's perspective: aquaculturist, fishermen, fisheries manager, trader, consumer or environmentalist.

Let's remember the simple reality. Poor fisheries management and increasing demand are the stimuli for aquaculture and innovation. The aquaculture sector has emerged to avoid mismanagement, minimize environmental shocks, control fish stock and fish growth rates, and manage to meet the market demand. Aquaculturists want to take control of production and marketing. They tend to do this through ownership, information and technology.

The emerging aquaculture sector tends to be more forward looking, rapidly growing, innovative, international and control oriented. It is shaping the future seafood sector through market, trade, production and environmental interactions.

AQUACULTURE AND FISHERIES INTERACTION IN THE ENVIRONMENT

Aquaculture and fisheries interact in several ways in the ecosystem:

- aquaculture can influence fish stocks through its use of wild fish stocks for inputs, such as feed, broodstock or juveniles;
- aquaculture and wild fish stocks can influence each other through disease transmission and other related interactions;
- aquaculture can influence wild fish stocks through intentional releases (e.g. salmon enhancement) or through unintentional escapes; and
- aquaculture can displace wild fish through its use of habitat (shrimp farms) or, in some cases, it can enhance fisheries habitat (e.g. some oyster operations build oyster reefs).

The following examples illustrate each of these interactions individually. Aquaculture can influence fish stocks through its use of wild fish stocks for inputs. Probably the most controversial example today is the use small pelagic fishes for fishmeal and fish oil. The growth of aquaculture and in particular, the culture of carnivorous fishes, has had a direct impact on the demand for fishmeal and fish oil. Fishmeal prices have traditionally traded in a range two to three times the price of soy meal. Recently, fishmeal has traded at levels more than six times the price of soy meal. The traditional relationship between fishmeal and soy meal has changed substantially. The empirical evidence indicates that the increased relative price of fishmeal and fish oil represents an important structural shift (Kristofersson and Anderson 2006). If fisheries are well managed, this implies an opportunity for the wild fisheries sector to increase net revenue. On the other hand, if fisheries are poorly managed, this implies increased risk of overfishing. In either case, the increased relative price for fishmeal and fish oil presents an incentive for innovation. We see this occurring in declining feed conversion ratios, especially in the case of salmon and the rapid development of new feed formulations.

Another way aquaculture uses wild fish stocks for inputs is when aquaculture uses wild juveniles for growout. For example, tuna farmers in Australia, Mexico and the Mediterranean capture wild juveniles and then fatten them in aquaculture cage systems. When the farmed shrimp industry started, it was heavily dependent on postlarval shrimp from the wild fisheries for stocking shrimp ponds. The farmed oyster and mussel industries depend heavily on wild seed. If not managed correctly, the use of wild stocks could have negative effects on wild fish stocks. On the other hand, the use of wild seed for oyster and mussel farming may actually help increase the stock of oysters and mussels because of increased survivability.

Aquaculture and wild fisheries have also interacted through the transmission of disease and by facilitating invasions of nonnative species. Here are some examples (See NRC (2004) for more detail related to oysters). The oyster disease MSX was introduced from Asia, and it contributed significantly to the decline of oysters in the Chesapeake Bay and elsewhere on the United States East Coast. Bonamiosis was introduced into France by oysters imported from North America. This introduction contributed considerably to the rapid decline of the French oyster farming industry in the 1970s. In both cases, part of the solution was introduction of oysters from Asia that were naturally resistant to the disease. Today the French industry is dependent upon *Crassostrea gigas,* an oyster from Asia, and officials are considering introducing farmed

Asian oyster, *C. ariakensis,* into the Chesapeake Bay. In both cases, the unfortunate invasions of introduced diseases have resulted in the use of farmed nonnative organisms to mitigate the problem.

Despite media attention to concerns related to the introduction of nonnative species, the introduction of nonnative species is common. White shrimp from South America have been introduced into Asia because they are resistant to white spot disease and are easier to grow than the native black tiger shrimp. Salmon have been introduced into Chile, New Zealand and Australia and have resulted in substantial industries in these countries. Channel catfish has been introduced from the United States to China. Tilapia, originally from Africa, has been introduced almost everywhere that has tropical climate.

Aquaculture has also been used to replenish or enhance fisheries through purposeful release of juvenile or adult fish. For example, the Japanese chum salmon fishery is almost exclusively dependent upon hatchery-based salmon. In Alaska, approximately 40 percent of the state's salmon harvest is dependent upon hatchery-based fisheries (Knapp, Roheim and Anderson 2007). However, although hatchery (aquaculture)-based capture fisheries may result in increased harvest, they also may facilitate inefficient harvest practices and create problems with genetic diversity and the integrity of truly wild stocks.

Hatchery fish do not face the same selective pressure as wild fish stocks and can compete directly with wild stocks for food and habitat. Wild salmon must swim up river and compete for a mate. In the hatchery, the eggs, fry and fingerlings face little selective pressure compared to their counterparts in the wild. Over the long run, this tends to result in declining wild fish stocks if the hatchery-enhanced fisheries are not carefully managed. Consider pink salmon in Prince William Sound (PWS), Alaska. In 1979, wild pink salmon accounted for over 90 percent of the total PWS harvest. However by 2004, the wild salmon harvest has declined to less than 10 percent of total harvest (ADFG 2007).

Aquaculture practices have had some extensive influence on habitat. For example, shrimp farms have had negative effects on mangroves and estuaries. Excessive finfish cage culture has resulted in the destruction of benthic habitat and in some cases has caused considerable pollution. On the other hand, there have been positive examples of aquaculture influence on habitat. Oyster culture has contributed positively to reef development that increases the diversity of fish in the area. Profitable fish farming has helped re-establish ecosystems, for example, mangrove replacement.

AQUACULTURE, FISHERIES, MARKETS AND TRADE

The aforementioned aquaculture/fisheries interactions indirectly influence the seafood market by changing the health of wild fish stocks and wild fish harvest. However, aquaculture also has a considerable direct influence through its impact on the market and international trade. For example, aquaculture has:

- influenced prices through increased supply;
- changed consumer behaviour, which has resulted in development of new markets;
- accelerated globalization;
- increased concentration and vertical integration in the seafood sector;
- resulted in the introduction of new product forms and improved quality and consistency;
- influenced the sector to become more forward thinking and market driven; and
- reduced price uncertainty and risk.

Evidence of price declines related to aquaculture can readily be seen by examining real price trends of aquaculture species. The real price trend for farmed fish species is going down. Competitive pressures in the last few years have led the prices of salmon, catfish and cod to converge (Urner Barry Publications 1990–2005).

An examination of seafood consumption in the United States will illustrate the influence of the aquaculture sector on seafood availability, changes in consumer behaviour and increasing concentration in fewer species. First, per-capita consumption of aquaculture species has increased remarkably over the last two decades. Consumption of shrimp (mostly farmed), the number one seafood, increased over 75 percent between 1987 and 2005. Consumption of salmon (mostly farmed), third in the ranking, went up 400 percent over the same time period. Consumption of farmed catfish (fifth on the list) increased by more than 90 percent, while tilapia (farmed), a species virtually unknown in 1987, is now number six. It is obvious that growth in seafood consumption is being fueled by aquaculture, while consumption of certain wild-caught species, such as cod, is declining. Thus, United States seafood consumption is currently dominated by imported aquaculture products. Second, seafood consumption in the United States is becoming concentrated on fewer species. The top five species accounted for 75 percent of consumption in 2004; in comparison, they accounted for only 56 percent of consumption just two decades ago. The top ten species comprised 71 percent of consumption in 1987; they now represent 93 percent. Why are we seeing the industry getting less complicated and more concentrated, at least in the United States and probably in many developed countries?

The explanation of the decline in prices and increasing concentration lies in the fact that growing markets and growing trade will come to those who can consistently deliver a high-quality product at stable or declining costs. In the seafood sector, this is what aquaculture producers have been doing for the past few decades. It can also be argued that sector diversity in the future is going to come from the "sauce" (i.e. the value-added component of the fish) and from image issues such as ecolabelling, rather than being created through the production of a large number of species. Thus, despite the fact that hundreds of different species are harvested – and will continue to be harvested – around the planet, in proportional terms more and more of the supply is going to be concentrated in fewer and fewer species. Likewise, more and more of the diversity is going to come from the marketers because, as you take control of and manage the fish, you can market it better and start selling additional attributes. By contrast, the traditional fisheries sector is going to experience many more difficulties in this category. Aquaculture operations tend to be managed for production and marketing control. Conversely, the wild sector is managed towards restricting access and harvesting the "right" amount to meet conservation goals. However, they are still failing to manage for quality and the market, yet it is clear that the sector that manages for these two factors will attain greater success in the market.

Another key point in this discussion has to do with the structure of costs. In the traditional fisheries, the primary costs are labour, fuel and maintenance of the boats. In the aquaculture sector, the primary costs are feed and fingerlings. This is an important difference, as aquaculture has immense opportunities to reduce costs through genetics research and feed substitutions. In contrast, fisheries have less room for cost improvement unless a move is made towards more efficient management, e.g. rights-based fishing. This is really a question of better management, biotechnology and related factors. The most impressive achievements have been attained in salmon aquaculture, but there is still much room for improvement with regard to production of tilapia and other new species.

This report will briefly touch on two species (salmon and tilapia) to emphasize the points made above. Farmed salmon production already accounts for over 70 percent of world supply, while the capture sector's harvest has remained relatively stable. Regarding United States imports of salmon, most of the growth in recent years has come in the form of boneless, skinless fillets produced primarily in nations with significant aquaculture industries. A natural consequence of having an industry where production systems are more highly controlled is that more value-added processing activities can occur. The industry is currently dominated by portion-control, value-added products. The negative media campaign against salmon aquaculture appears to have had some limited impact on demand. However, an analysis of these recent developments is beyond the scope of this report. For the purposes of this discussion, the point that must be emphasized is that salmon aquaculture has moved forward and gained market share despite the negative media, and yet there is still room for wild salmon – both the low-end (pink and chum salmon) and in the specialty/premium (chinook, coho and sockeye) segments

Tilapia also supports strong aquaculture industries in developing countries (Egypt, Philippines, Indonesia, China). As observed previously with salmon, United States imports of tilapia are experiencing a shift from whole to processed fish. Tilapia is seen as a substitute for flounder, snapper and all kinds of white fish. In addition, many environmental groups actually favour tilapia.

CONCLUSIONS

- Aquaculture enters when fisheries have failed to meet market demands.
- Growth in the seafood industry will be fueled by aquaculture imports.
- Aquaculture is forcing change in fisheries:
- through competition (supply);
- by developing new technology (hatchery-based fisheries);
- by example (quality control); and
- by creating new demand – both for inputs (fishmeal) and outputs (seafood).
- There will be increases in per-capita seafood consumption; however, consumption will be concentrated on fewer species, with diversity coming in the "sauce" and with labelling issues, such as organic and ecolabelling.
- Growth of aquaculture parallels a shift in the market towards value-added products.
- Technology, innovations, better nutrition and disease management will continue to reduce costs in aquaculture. Lower production costs will increase supply from aquaculture and hold prices down for all fish. The trend towards value-added creation will drive processing to countries where labour costs are low.
- Despite criticism from environmental organizations, aquaculture will not go away. The potential constraints for aquaculture development, in particular the fishmeal, will be circumvented by new technology and substitution.
- Aquaculture will dominate the commodity market, but there will be increasing opportunities for wild-market products in the upper-end segments, especially the niche market.
- In the long run, all significant commercial seafood supplies will come from one of three sources:
  - fish farms/aquaculture;
  - aquaculture-enhanced fisheries; and
  - fisheries that adopt systems of management that are more like aquaculture management; clearly define rights and responsibilities; incorporate principles of husbandry, range management, forestry and farming; and are more market and quality driven.

REFERENCES

ADFG. 2006, 2007. *Prince William Sound annual management reports*. Alaska Department of Fish and Game.

FAO. 2005–2006. *FishStat plus – universal software for fishery statistical time series*. Rome, (http://www.fao.org/fi/website/FIRetrieveAction.do?dom=topic&fid=16073&lang=en)

Knapp, G., Roheim, C.A. & Anderson, J.L. 2007. *The great salmon run: competition between wild and farmed salmon.* Washington, DC, Traffic North America, World Wildlife Fund.

Kristofersson, D. & Anderson, J.L. 2006. Is there a relationship between fisheries and farming? Interdependence of fisheries, animal production and aquaculture. *Marine Policy*, 30: 721–725.

NFI. 2005. *Top 10 U.S. consumption by species chart*. McLean, VA, National Fisheries Institute.(http://www.aboutseafood.com/media/top_10.cfm)

NRC. 2004. *Nonnative oysters in the Chesapeake Bay*. Washington, DC, National Academy of Sciences Press.

Urner Barry Publications. 1990–2005. *Seafood price-current*. Toms River, NJ, Urner Barry Publications, Inc.

USDC/NMFS. 2003. *Fisheries of the United States 2003*. Current Fishery Statistics No. 2003. Silver Spring, MD, Fisheries Statistics Division, United States Department of Commerce/National Marine Fisheries Service.

USDC/NMFS. 2006–2007. *U.S. foreign trade*. Silver Spring, MD, Fisheries Statistics Division, United States Department of Commerce/National Marine Fisheries Service (http://www.st.nmfs.gov/st1/trade/index.html).

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Gunnar Knapp is a Professor of Economics at the University of Alaska Anchorage Institute of Social and Economic Research, where he has worked since receiving his PhD in Economics from Yale University in 1981. Dr Knapp has researched a wide variety of topics on the economy of Alaska and the management of markets for Alaska natural resources. Since 1991, much of his research has focused on markets for Alaska salmon and how they have been affected by the competition from farmed salmon and other factors. He has also studied the changes in the Alaska salmon industry over this time, and how fishermen, processors, fishery managers and politicians have responded to change. In connection with his research, Dr. Knapp has traveled widely within Alaska and other wild and farmed salmon producing regions. Together with Professors Cathy Wessells and Jim Anderson of the University of Rhode Island, Dr Knapp wrote the recently released report *The Great Salmon Run: Competition Between Wild and Farmed Salmon*, which was published in February 2007 by TRAFFIC North America (www.traffic.org).

Implications of aquaculture for wild fisheries: the case of Alaska wild salmon

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ABSTRACT

Worldwide aquaculture production is growing rapidly. The experience of Alaska wild salmon suggests that aquaculture may have significant and wide-ranging potential implications for wild fisheries. Salmon farming exposed wild salmon's natural monopoly to competition, expanding supply and driving down prices. Wild salmon has faced both inherent as well as self-inflicted challenges in competing with farmed salmon. The economic pressures caused by competition from farmed salmon have been painful and difficult for the wild salmon industry, fishermen and communities, but these pressures have contributed to changes that have helped make the salmon industry more economically viable. Farmed salmon has greatly expanded the market and created new market opportunities for wild salmon. Farmed salmon has benefited consumers by lowering prices, expanding supply, developing new products and improving quality of both farmed and wild salmon. Salmon farming has had no apparent direct effects on Alaska wild salmon resources, but could have indirect effects on wild salmon resources that might be positive or negative. The experience of Alaska wild salmon suggests that anyone interested in wild fisheries should pay close attention to what is happening in aquaculture. No wild fishery market – especially for higher-valued species – should be taken for granted.

INTRODUCTION

An aquaculture revolution is happening in the world seafood industry. Aquaculture accounts for an ever-growing share of world seafood production. One of the most important questions facing wild fisheries is how they will be affected by the development of aquaculture.

Salmon is one of the species for which the growth in aquaculture production has been most dramatic. Alaska is the world's largest producer of wild salmon. Between 1980 and 2004, farmed salmon's share of world salmon supply grew from 2 percent to 65 percent, and Alaska's share fell from 42 percent to 15 percent. The experience of the Alaska wild salmon industry during this time provides insights into how aquaculture may affect wild fisheries.

A BRIEF OVERVIEW OF THE ALASKA WILD SALMON INDUSTRY

In recent years, Alaska salmon harvests have averaged about 350 000 tonnes (Figure 1). Over the past two decades harvests in most Alaska salmon fisheries have been very strong. Alaska wild salmon fisheries are certified as sustainable by the Marine Stewardship Council.

FIGURE 1
World supply of wild and farmed salmon

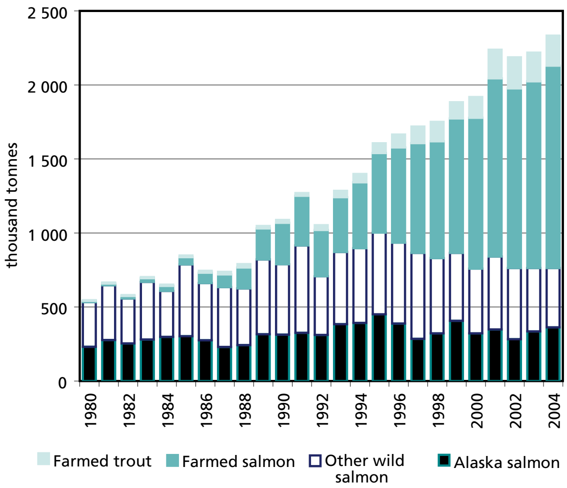


FIGURE 2
Alaska Seafood Marketing Institute advertisement for Alaska wild salmon

Five species of Pacific salmon are harvested in Alaska. Pink salmon accounts for the largest share of volume, followed by sockeye, chum, coho and chinook. Sockeye salmon – which commands much higher prices than pink or chum – accounts for the largest share of ex-vessel value.

Alaska wild salmon are processed into four major primary products, including frozen salmon, canned salmon, fresh salmon and salmon roe. These products are sold in markets all over the world (Figure 2). In recent decades, the most valuable markets have been the Japanese frozen salmon market (for sockeye salmon), the European and the United States canned salmon markets (for sockeye and pink salmon), the United States market for fresh and frozen salmon, and the Japanese market for salmon roe.

Alaska wild salmon are harvested in 26 gear and area-specific fisheries by small boats utilizing four major types of fishing gear (seine, drift gill net, set gill net and troll). Participation is restricted by a limited entry management system. About 20 000 fishermen work seasonally in Alaska salmon fishing. Alaska's coastal communities are heavily dependent on salmon fishing for fishing and processing jobs and for tax revenues.

There is no salmon farming in Alaska. Salmon farming – and all finfish farming – is banned in Alaska. It was banned partly to protect wild salmon resources and partly to protect fishermen from economic competition from farmed salmon.[1]

For many or most Alaska salmon fishermen, salmon fishing is more than just a job. They love salmon fishing in part because it allows them the chance to work and live independently in remote places of great beauty. In the late 1980s, Alaska salmon fishermen enjoyed not only these benefits but also unprecedented higher prices and incomes.

TEN LESSONS FROM THE EXPERIENCE OF ALASKA WILD SALMON

I would like to suggest ten lessons from the experience of Alaska's wild salmon industry about the implications of aquaculture for wild fisheries.

1. Aquaculture can have rapid and dramatic negative effects on markets for wild fisheries

Competition from farmed salmon was the most important cause of a dramatic decline in Alaska salmon prices from the late 1980s to 2002. By 2002, real (inflation-adjusted)

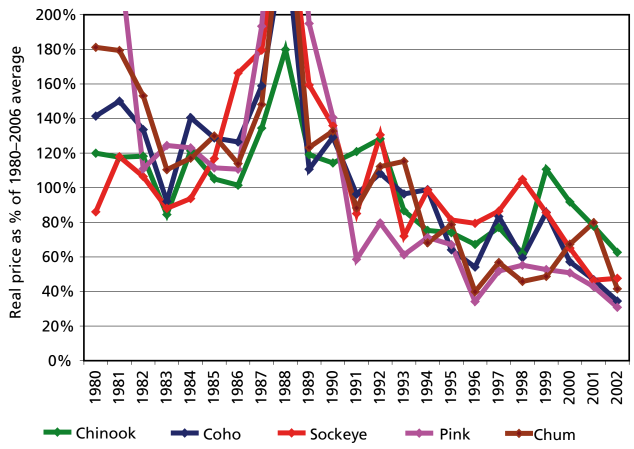
[1] Although salmon farming is banned, Alaska does have a large-scale salmon hatchery programme. Hatchery releases account for about one-third of Alaska salmon harvests.

ex-vessel prices for most Alaska salmon species had fallen to about one-third of average prices during the 1980s (Figure 3). [2]

For example, during the 1990s, farmed salmon rapidly replaced wild sockeye as the dominant product in the Japanese market. As the total supply of salmon to the Japanese market increased, the Japanese wholesale price of Alaska sockeye salmon declined dramatically (Figures 4 and 5). As the wholesale price in Japan declined, the price to the Alaska fisherman also declined.

FIGURE 3

Indexes of real Alaska salmon ex-vessel prices, 1980–2002



2. Changes caused by competition from aquaculture may be painful and difficult for those who depend on wild fisheries

There were many difficult adjustments for Alaska fishermen as they experienced increasing competition from farmed salmon. As salmon prices declined, their incomes declined, as did the value of their boats and limited entry permits. Many fishermen lost their markets as declining profits resulted in the closing of many processing plants. Fishing communities experienced a loss in fishing taxes and population as processing plants closed and fishermen moved away, and through social stresses such as alcohol abuse. The political influence of the salmon fishing industry declined, and pressures grew to reallocate salmon from commercial fisheries to other uses such as sport fishing.

Many Alaska salmon fishermen blamed these problems upon competition from farmed salmon. They view farmed salmon as an inferior product that has harmed them. They believe that salmon farming in other places is harmful to the environment and unfairly subsidized. Car bumper

FIGURE 4

Japanese "red-fleshed" frozen salmon imports and wild sockeye wholesale price, 1986/87 to 2004/05

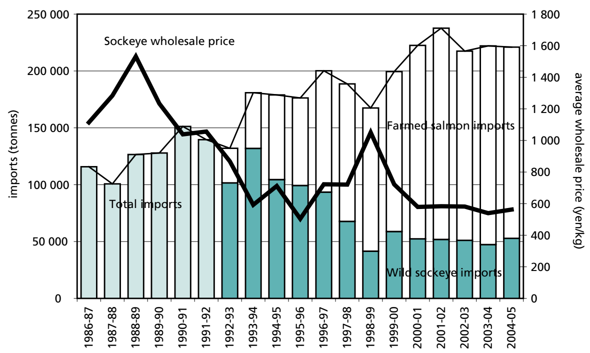
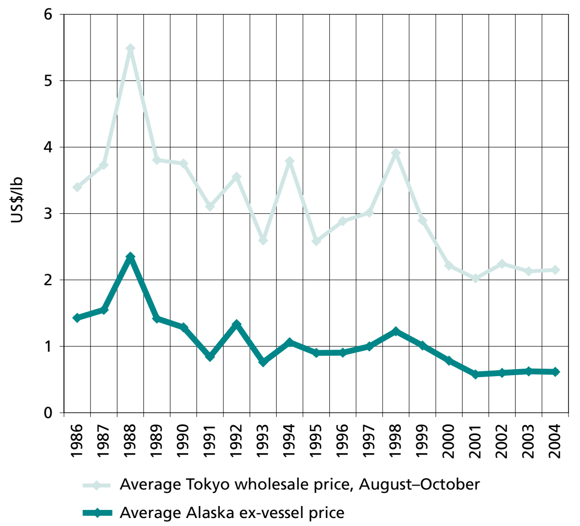


FIGURE 5

Japanese wholesale prices and Alaska ex-vessel prices for sockeye salmon, 1986–2004



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2 Farmed salmon was not the only cause of the decline in prices for wild Alaska salmon. Many other factors also contributed to the decline, including large Alaska salmon harvests, growing exports of Russian salmon, a recession in the Japanese economy and stagnant consumer demand for canned salmon.

FIGURE 6
Two examples of car bumper stickers

FIGURE 7
Alaska sockeye salmon harvests: projected and actual, 1980–2006

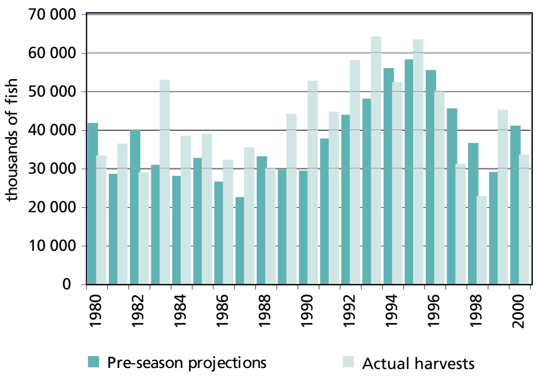


FIGURE 8
Idle fishing boats

The fact that many Alaska fishing boats and processing plants are idle for much of the year is a huge cost disadvantage.

stickers such as those shown in Figure 6 are commonly seen.

I think it is typical and natural for people who are suffering economic harm from competition to look for someone to blame – and to ask their government to help and protect them. However, when you are facing competition I think that the only real long-term solution is to understand better what your customers want and to work even harder to provide them what they want.

3. In an increasingly globalized economy, the market effects of aquaculture on wild fisheries occur regardless of where the aquaculture is happening

Alaska wild salmon are sold in global markets. The decline in Alaska sockeye salmon prices was caused by farmed salmon production in a foreign country for export to another foreign country (Chilean and Norwegian exports of farmed salmon and trout to Japan). Banning salmon farming in Alaska did not keep it from happening. Banning United States farmed salmon imports would not have kept it from happening.

4. Wild fisheries may face significant inherent challenges in competing with aquaculture. These challenges derive from the fact that aquaculture producers have much greater control over production

Inconsistent and unpredictable supply makes it much more difficult for wild salmon producers than for farmed salmon producers to meet buyers' supply needs and to plan for marketing. Alaska wild salmon catches vary widely from year to year, and often vary widely from the preseason catch predictions (Figure 7). In contrast, salmon farmers know exactly how many fish they will have to process and to market – and who can choose when to process and market them.

The seasonality of wild salmon fisheries increases production costs relative to farmed salmon, and makes it relatively more difficult to market wild salmon (Figure 8). Sometimes so many salmon are harvested in a day that there is no practical processing option other than canning. There are not enough planes to fly the salmon to a fresh market, and there are not enough freezers to freeze them.

Wide variation in sizes and quality increases costs of processing and marketing wild salmon.

FIGURE 9
Bruising may occur as salmon are "picked" from gillnets

5. Competition with aquaculture exposes not only inherent but also "self-inflicted" challenges in wild fisheries

There are significant quality problems in many Alaska salmon fisheries resulting from practices at many different stages of fishing, tendering and processing. These include, for example, bruising that occurs as fish are removed from gillnets (Figure 9), poor handling as fishermen focus on working fast rather than handling fish carefully, long delivery times between when fish are caught and when they are processed, and lack of refrigeration or icing on fishing boats.

In some Alaska salmon fisheries there are many more boats fishing than are needed to catch the fish (Figure 10).

Competition with aquaculture exposes these problems. When customers for Alaska salmon have alternative sources of supply, they are less willing to accept quality problems with Alaska wild salmon. When prices fall, it is harder to ignore how traditional ways of fishing add to costs.

FIGURE 10
Crowding in Alaska's highly competitive Bristol Bay drift net fishery

Photographs by Bart Easton

6. Economic pressures caused by aquaculture may contribute to changes that make wild fisheries more economically viable

In the Alaska salmon industry, as fishermen and processors have left the industry, costs have fallen and efficiency has increased. Quality has improved in many fisheries. Marketing efforts have expanded. The salmon industry has worked harder to understand and meet the needs of customers.

7. Over the longer term, aquaculture may benefit markets for wild fisheries by expanding markets and creating new market niches for wild fisheries

As salmon farmers have expanded world supply of salmon, they have also greatly expanded world demand for salmon. Salmon farming has made salmon much more widely

FIGURE 11
Indexes of real Alaska salmon ex-vessel prices, 1980–2006

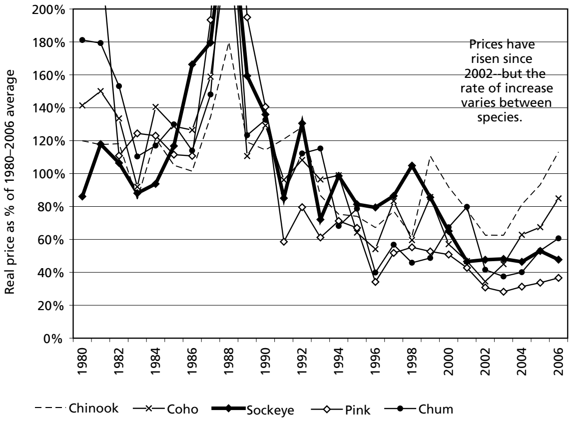
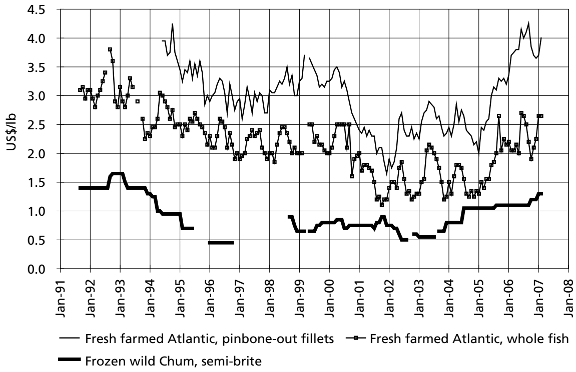


FIGURE 12
US wholesale prices for selected wild and farmed salmon products, January 1991 – January 2007



available – in more countries and more stores, throughout the year. Salmon farming has created new salmon consumers and new product forms. Growing demand is creating growing niche market opportunities for high-quality wild salmon. Since 2002, strong demand has contributed to a rebound in prices for both farmed salmon and Alaska wild salmon (Figure 11).

8. Aquaculture benefits consumers by lowering prices, expanding supply, developing new products and improving quality of both farmed and wild fish

Since the development of salmon farming, both farmed and wild salmon have become cheaper and available more consistently, over a far larger geographic region, in more stores and restaurants and in more product forms (Figure 12).

9. Aquaculture may have both direct and indirect effects on wild fishery resources, which may be either positive or negative

The experience of Alaska wild salmon suggests that aquaculture may affect wild fishery resources in several different ways. Salmon farming critics have pointed out the potential for salmon farming to introduce diseases among wild salmon populations or for escaped salmon to introduce non-native salmon species or to affect wild salmon genetic diversity. However, because there is no salmon farming in Alaska, none of these direct effects have occurred in Alaska.

Aquaculture proponents have suggested that fish farming may benefit wild fishery resources by lowering prices and thus fishermen's incentives to overexploit wild fishery resources. However, because Alaska salmon fisheries are well-managed, they are not over-exploited, and there is little evidence that lower prices have significantly reduced fishing catches or benefited salmon resources.

A potential indirect effect of competition from salmon farming is that lower salmon prices may reduce economic and political incentives to protect salmon resources and the environment on which they depend. When Alaska wild salmon were very valuable, there was a very strong commitment protecting salmon resources and the environment upon which salmon depend. But as the economic value of salmon has fallen, funding for salmon management and research has fallen, and there is greater support for proposed mining and oil development projects in salmon-producing regions.

10. The experience of Alaska wild salmon suggests that anyone interested in wild fisheries should pay close attention to what is happening in aquaculture. No wild fishery market – especially for higher-valued species – should be taken for granted

Aquaculture will continue to grow rapidly because it can meet market demands for predictable, year-round and growing supply of high-quality seafood. The challenges to wild fisheries posed by aquaculture will increase over time.

EFFECTS OF SALMON FARMING ON THE ALASKA SALMON INDUSTRY: TWO CONTRASTING PERSPECTIVES

I will close by contrasting two different perspectives about how the Alaska wild salmon industry has been affected by salmon farming. The first perspective, which I call the "popular/green/Alaskan" perspective, is often reflected in the press and is commonly heard in Alaska:

Unfairly subsidized and inferior farmed salmon harmed the environment and wild stocks in producing nations, and flooded world markets, depressing wild salmon prices and significantly harming Alaska fishermen and fishing communities.

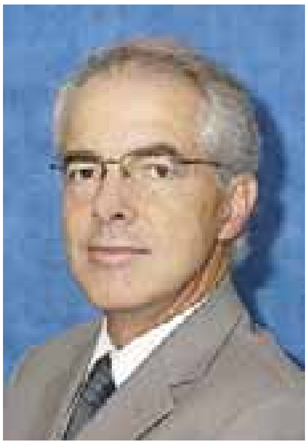
My own perspective, which I call the "economic perspective," is different:

Salmon farming exposed a "natural" monopoly to competition, benefiting consumers by expanding availability, lowering prices, spurring innovation and market development, and leading to a more efficient wild salmon industry more focused on meeting market demands.

I do not mean to imply that competition from salmon farming has been easy for the Alaska salmon industry. It has not. It has been very difficult. But in the end, I think the Alaska salmon industry can and will change, survive and compete successfully in the very different world salmon market that salmon farming is creating – and will better serve the world's consumers.

Jonathan Shepherd

Director General
International Fishmeal and Fish Oil Organisation



Jonathan Shepherd is a qualified veterinarian with a doctorate in aquaculture economics. He has held general management posts associated with aquaculture, including for the British Petroleum, Unilever and Norsk Hydro groups. Jonathan was Group Managing Director of the Danish fish feed company BioMar until appointed Director General of the International Fishmeal and Fish Oil Organisation in 2004. He is married and lives in London.

The lessons from intensive livestock development for aquaculture

Jonathan Shepherd
International Fishmeal and Fish Oil Organisation

ABSTRACT

Aquaculture production has some inherent biological advantages over land animal production in terms of efficiency. However, the difficulty of providing a truly controlled environment for aquaculture also brings some disadvantages. The developmental steps in conventional livestock production are being now recapitulated by the aquaculture industry but at a much faster rate. From the first step of simply producing enough food for the population, these include modernization (from backyard to farm-scale), the emergence of concern issues (e.g. biodiversity; environmental pollution), through to the growth of added-value products based on quality, convenience etc. The developments in modern poultry production are briefly considered, including key improvements in nutrition, genetics and breeding, health care and management. Lessons are drawn for future development in aquaculture production. Finally attention is paid to the big issues currently affecting the value chains for meat and aquaculture production.

INTRODUCTION

Commercial agriculture has developed over millennia, whereas modern aquaculture has largely developed over the past 30 years. Modern intensive poultry production only started to develop in the 1950s, but at that stage there was little, if any, interest in environmental, welfare and food safety issues, whereas modern aquaculture has been faced with these challenges from the outset. The fact is that aquaculture is the fastest growing food sector, even if it may be struggling a little with its image in some quarters.

Fish farming was probably first practiced as long ago as 2000 BC here in China, and in 475 Fan Lai produced his Chinese treatise on carp culture. China has led the world in aquaculture, and the more extensive systems will continue to play an important role in some countries. However, I have been asked to speak about the lessons from intensive livestock development of land animals for aquatic animals, and I will therefore restrict myself to modern intensive systems of aquaculture. That is not to say there won't be a continuing role for traditional more extensive systems of aquaculture under certain circumstances, but with economic development it becomes more difficult to justify in terms of resource allocation and utilization.

How does one define modern intensive livestock development? The factors usually taken into account include stocking and production intensity, closed life cycle, compounded diets, environmentally controlled housing etc. to enable optimized growth via control of inputs resulting in controlled and marketed output. This approach also lends itself to continuous improvement. Note that the different inputs to the cost of production (Figure 1) apply to both intensive fish and intensive poultry production.

FIGURE 1
Inputs to the cost of production

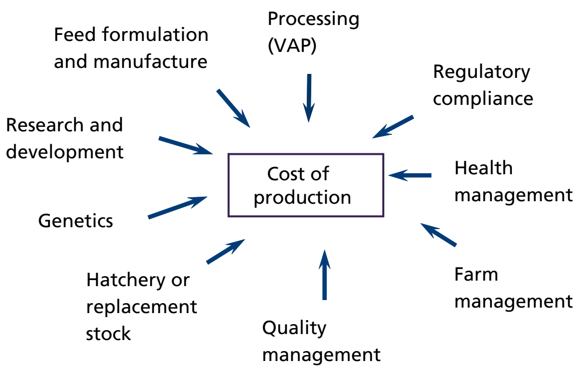
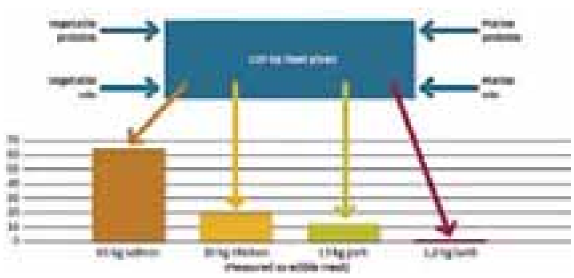


FIGURE 2
Efficient production of proteins



Source: Kontali

The consumption of poultry meat has outstripped the rising trend of animal protein consumption, which in turn was a result of animal protein becoming more universally affordable. Worldwide pork consumption currently stands at 100 million tonnes, poultry at 80 million tonnes, beef at a little over 60 million tonnes and eggs close to 60 million tonnes. By comparison, according to FAO (2006a), global aquaculture production in 2005 was 48.8 million tonnes compared with a total fishery capture figure of 93.8 million tonnes, with aquaculture representing 34 percent of total world fisheries in 2005.

HOW DOES AQUACULTURE DIFFER FROM LAND ANIMAL HUSBANDRY?

Compared with land animal farming, fish farming is a much more varied activity with many more species farmed, each having different characteristics. At the same time, fish and invertebrates alike recapitulate their evolutionary history in the water instead of *in ovo* or *in utero* as do warm-blooded animals, so growing fish requires attention to larval survival and larval feeding, which imposes constraints on successful rearing from egg

Fish are inherently more efficient converters due to being cold-blooded. Fish do not waste energy counteracting gravity or moving about on land. Fish catabolism and reproduction are also more efficient than that of land animals. Figure 2 illustrates how efficient farmed salmon are as protein converters compared with farmed land animals. The amount of dietary protein and energy retained by farmed salmon is approximately twice that retained in chicken and pigs, which are the most efficient terrestrial converters (Aasgaard and Austreng 1995).

The yield of edible meat is often higher in fish. Losses from removal of the viscera at processing depend on species, with carnivorous fish having shorter intestines and lower gut-out (e.g. 10 percent in salmon) than herbivores. But of course fish do not need heavy bones to bear weight or walk about on land so their bones are lighter. Carcass yields vary but typical values are: poultry 0.7–0.8, pigs 0.7–0.8, cattle 0.5–0.6, sheep 0.5 and fish 0.7–0.8. On the other hand, it is more difficult and costly to maintain a controlled environment for fish and hence to maintain biosecurity, control escapes of fish stock and waste material etc. The use of onshore tanks is largely impractical for marine fish due to extra investment and pumping costs, although exceptions occur (e.g. farmed flatfish). Also, postharvest preservation and distribution can be more challenging than that of warm-blooded livestock.

THE FOUR DEVELOPMENT STAGES OF ANIMAL HUSBANDRY

The development of animal husbandry can be simplified to cover four different steps: producing enough food to feed the population, modernization, the emergence of concern issues and adding value.

For example, producing enough food was the immediate priority in parts of Europe straight after World War II and remains so today in many poorer parts of the developing world where subsistence agriculture is often the norm.

The first step in modernization typically occurs when there is a transition from small family farms to large farming enterprises. A greater proportion of feed inputs and replacement stock are bought-in, and farmers start to specialize in specific aspects of production. Also there is increased mechanization and use of fossil fuel energy. Demand and production of livestock products are increasing rapidly in developing countries, which have outpaced developed countries. This increasing demand is associated with important structural changes in countries' livestock sectors, such as intensification of production, vertical integration, geographic concentration and up-scaling of production units.

In developed economies, issues such as antibiotics/chemicals, biodiversity, pollution, animal welfare etc. have come to the fore. In recent years, the scare over bovine spongiform encephalitis (BSE) or "mad cow disease" has shown the dramatic consequences of ill-considered recycling of agro-industrial byproducts (meat and bone meal) as animal feed. The incident and its media coverage have also brought new livestock feeding practices to general public attention. This and similar events, such as dioxin contamination of broiler meat in some European Union (EU) countries, have created widespread consumer distrust in the industrial livestock sector. In China, livestock production is starting to modernize and already these concern issues are important (e.g. antibiotic residues; melamine contamination), especially for those food companies exporting to western countries.

Powered by large food retailers, factors such as convenience, quality, safety assurance, the use of non-genetically modified ingredients, and even taste etc are now important as means to add value to food products. Large food processing and retailing firms are becoming dominant in the meat and dairy trade, achieving economies of size and scope, integrating vertically and securing market ownership. As a result, the requirements of integrated food chains in terms of volume, quality, safety etc. are becoming pervasive throughout the livestock sector.

In summary the livestock sector has been transformed by technology, including:

- by the effect on productivity of the widespread application of advanced breeding and feeding;
- by irrigation, fertilization and plant breeding, which have meant much higher yields and improved nutritional properties in fodder crops used for feed;
- by increased use of fossil fuel, which has helped to improve productivity; and
- by modern information technology and other technical changes, which are improving post-harvest, distribution and marketing of animal products.

AQUACULTURE FOLLOWING SAME STEPS BUT MUCH FASTER

The hunting of fish and the problem of static or declining fish stocks represent an uncertain and erratic way to meet demand consistently on a long-term basis. This helped to encourage pioneering investment in Atlantic salmon farming salmon in the 1960s, and the industry took off in the 1980s as retailers and restaurant chains became able to place contracts for a year-round supply of consistent product. In the same way, tilapia farming is now being powered by the demand for bland white fillet in order to make prepared dishes in the United States. Aquaculture growth is now focusing more on higher-value species reared for profit on a capital-intensive basis in purpose-built facilities.

The recent history of this expansion is characterized by industrialization and commoditization. The dramatic change in supply of farmed salmon and the decline in farm gate price and decline in production costs are shown in Figure 3. I may add that the consumer has seen a rather smaller drop in the retail price.

At the same time, concerns have arisen about threats to the environment from aquaculture. These include pollution, escaped fish, damage to mangroves, sustainability questions etc. In summary, aquaculture has gone through the same development steps

FIGURE 3
Farmed salmon: production volume, cost and farm-gate price

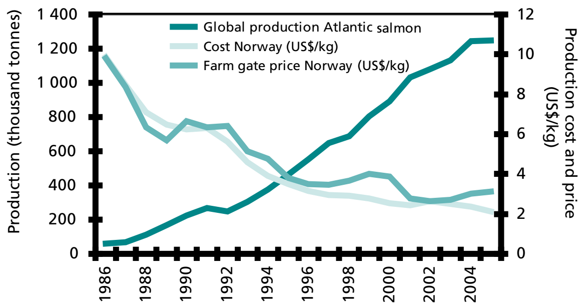
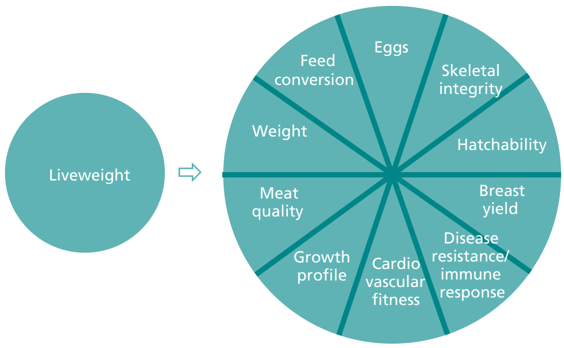
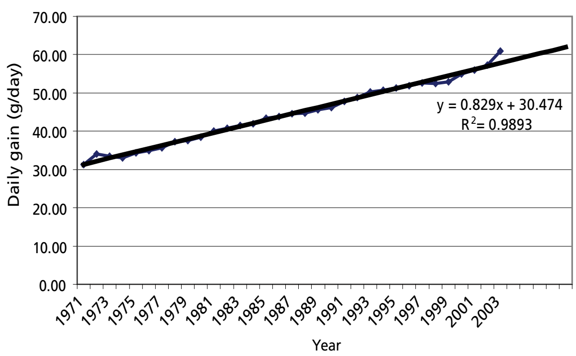


FIGURE 4
Evolution in broiler breeding genetics



After Laughlin (2007); courtesy of Aviagen

FIGURE 5
Change in poultry LWG over time



Laughlin (2007) based on NFU Broiler Bulletins

as land animal husbandry but has done so in a few decades instead of many centuries.

KEY DEVELOPMENT TRENDS IN POULTRY PRODUCTION

An example of the many improvement trends from among land animal species is given by milk production from cows (which has improved by 45 percent in last 20 years), and there have indeed been centuries of observational selection for better livestock. However, I will now focus on poultry, where the changes have been the most dramatic and where it is perhaps easiest to make comparisons and draw parallels with intensive aquaculture.

Nutrition

How much of the performance gains over the past 50 years have been due to genetics and how much is attributable to improvements in feed formulation, environmental control and husbandry systems? Havenstein, Ferket and Qureshi (2003) compared modern strains of broilers with a control strain established in 1957. By using also 1957 and 2001 feed specifications, they concluded that for growth rate, carcass and parts yield, the genetic selection brought about by commercial breeding companies had contributed 85 to 90 percent of the change over 45 years, while nutrition had provided 10 to 15 percent of the change. For feed conversion and mortality, this estimate was more difficult since age and weight must be allowed for, but the modern strain required 15 percent less feed for each unit of gain on the modern diet than the 1957 diet. Combining genetic and nutritional influences, the modern strain grew to an identical weight in one third of the time with a three times better food conversion ratio (FCR).

Genetics and breeding

In the last 40 years the genetic selection programmes for poultry have become increasingly sophisticated, achieving rapid balanced progress. Since the 1960s where live-weight was almost the only trait selected for, the number of traits has greatly increased, covering not only production traits but also traits related to the physical and metabolic support, survival and health of the selected bird. Figure 4 shows development of trait inclusion in a modern poultry-breeding programme. In the same paper in which this figure appeared, Laughlin (2007) also re-looked at United Kingdom's poultry performance data since 1971 based on the breeds used across the industry at any time. The production data (Figure 5) reflect a remarkably consistent linear improvement in both daily liveweight gain (LWG) and FCR. The regression line (R^2 = 0.99) indicates an annual improvement (in the field) of 0.83 g per day per year – equivalent to 37.5 g per day to 42 days.

FCR data represent a major contribution to the profitability of the industry in terms of reduced feed inputs, as well as in waste output. Overall it seems that breeding companies have effectively dominated much of poultry industry development by their strategic choices regarding directed genetic selection of commercial traits.

Health

Breeding for disease resistance has played a major role in overcoming infectious poultry diseases (e.g. salmonellosis) as well as metabolic diseases. A good example of the latter is tibial dyschondroplasia causing lameness in fast-growing broilers, which has been shown to be heritable and successfully reduced by selection. As specific poultry vaccines have replaced the need for routine medication, use of antibiotics has fallen and many flocks do not even receive antimicrobial growth promoters.

Management

None of the above developments would have been possible without good housing and husbandry practices. For example, at the same time as the developments in genetic science were occurring, various reproductive technologies were developed (e.g. artificial incubation and hatching, lighting programmes to enable year-round production, and artificial insemination). These techniques were essential to enable the development of the production industry.

Due to close control and continuous improvement, the financial implications and performance variations of only 1 or 2 percent are measurable, known and acted upon. In this regard, the poultry industry is significantly ahead of other agricultural livestock sectors. Also, willingness to supply and share data – anonymously – for benchmarking has been shown to be of considerable value to cost reduction in the United States poultry industry (c.f. salmon farming industry in Norway).

WHAT CAN WE LEARN FROM LAND ANIMAL PRODUCTION?

Technology is the key to intensification and to industrialization

Breeding and genetics have been the key to cost-efficiency in poultry, and these tools are now being applied to farmed fish. For example, Gjedrem (1997) estimated that the time taken to reach a harvest weight of 3.5 kg had been shortened by 1 month per generation as a result of the Norwegian salmon-farming programme. Although initial focus has been on improved LWG, FCR, disease resistance and delayed maturation, attention has moved to aspects of flesh quality that help to determine appearance, presentation, texture and taste (R. Alderson, personal communication). By comparison with poultry, the longer generation time of salmon means that selection work takes longer, albeit much faster with tilapia than salmon. But as things stand, much of aquaculture largely depends on wild strains of fish.

Nutrition is, of course, vital and there are still a lot of gaps in our knowledge of the requirements of most aquaculture species. But once again we have gained a lot of knowledge and technology from land-based agriculture, particularly poultry, in many different areas, including basic nutritional knowledge (e.g. amino acid requirements), milling technology and nutritional technology (e.g. best-cost feed formulation, reduction in antinutritional factors etc).

However, there are a number of major differences when it comes to aquaculture diets compared with agricultural diets, including the importance of protein and fats in the energy requirements of most fish and the poor use they make of carbohydrates, the problems of pellet stability and nutrient leaching in water, and the environmental problems produced from wasted feed.

With the intensification of aquaculture, there has been a steady move away from extensive feeding systems relying on the fertilization of the water and the consequent primary production, as well as from the feeding of moist feeds consisting of milled plant material and trash fish. Intensive aquaculture relies instead on formulated, pelleted diets that give better biological performance and biosecurity (quality control, hygiene, stability, storage etc.) as well as less environmental pollution. This global trend is likely to continue.

As with land animals, good husbandry is the paramount consideration in fish health management, including preventive medicine to keep pathogens out and boosting the immune status of fish. However, there are special challenges, depending on species. For example, shrimp have a more primitive immune system than finfish, and different approaches to vaccination are therefore needed. Lessons have been learnt from BSE and laws introduced in Europe to prevent intra-species recycling of disease by feeding back to farmed fish processed offals derived from the same species. The importance of biosecurity cannot be over-emphasized, as much in fish as in poultry.

In the early days of salmon farming in Europe, health problems threatened to kill off the industry. The answer was a combination of vaccines (injecting each smolt prior to seawater transfer using poultry multi-dose equipment) and good husbandry. This involved the use of single-year-class sites, fallowing periods after harvesting and site rotation, with the added benefit that antibiotic use fell dramatically. Unfortunately it seems that some of these hard-won lessons are being forgotten as salmon farming has expanded elsewhere.

Supply chain management

Just like poultry, successful industrial fish farming is all about management of the supply chain to provide continuity of supply for the customer. The key steps include raw material procurement, farm management, processing and distribution, while at the same time other supply chain issues, including quality assurance and verification that procedures are being followed (e.g. HACCP and ISO standards). Figure 6 illustrates how a major fish feed supplier (BioMar Group) views food safety and traceability in the aquaculture value chain.

FIGURE 6
Food safety and traceability in the aquaculture value chain

Source: Biomar annual report 2006

Avoiding food scares

Managing quality and risks and avoiding food scares is crucial, whether from disease (e.g. the effects on consumer demand from BSE of cattle and avian flu) or from contaminants (e.g. dioxin in poultry). International food scares are part of the price of globalization and occur with depressing regularity followed often by catastrophic falls in market demand, sometimes for long periods. This is linked to supply chain management via auditing of raw materials and of their suppliers, as well as full chain traceability. Note that new EU rules ensure a foodstuff can be tracked from either soil to table or from water to table – and back again. The problem is that one rogue farmer, supplier or distributor can wreck the market for an entire industry that is otherwise doing a good job using best management practices.

Marketing

On the industrial scale, producers need to forge strong relationships with food processors, distributors and retailers, i.e. form partnerships along the value chain. Aquaculture needs to think value chains and to understand the drivers on food habits and consumer acceptance (e.g. price, convenience etc). They must also bear in mind that supermarkets are fighting aggressively among themselves for market share, which includes altering the perceptions of their customers on various issues. Following food scares, at least in Europe, the public may appear to trust supermarkets more than they trust governments.

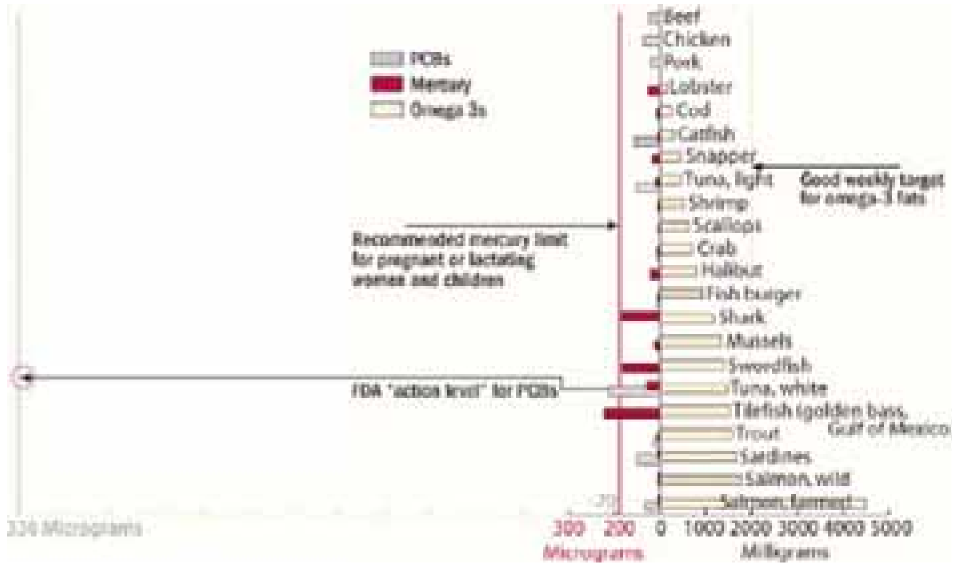
On the more local scale, there is a wide range of opportunities due to the diverse range of aquatic species. In the future, it's likely that over 80 percent of products will be from less than 10 aquaculture species. However, the many other "minor" species could well continue to be exploited on a more local level from outlets offering "niche products" (e.g. organic fish akin to free range chicken products; premium fish via restaurant/catering channels etc.).

AQUACULTURE AND HEALTHY EATING

We must remember that intensive aquaculture is a very recent phenomenon and has come a tremendously long way in a short time. Of course problems have arisen and mistakes have occurred, while laws and codes of practice were put in place to cope with all this. Not surprisingly there have been institutional problems and a lack of organizational support – while FAO has been at the forefront in addressing this (the Network of Aquaculture Centres in Asia-Pacific (NACA) is the only regional intergovernmental organization that promotes aquaculture and the Committee on Fisheries (COFI) Subcommittee on Aquaculture is the only global intergovernmental forum that discusses aquaculture exclusively). Also aquaculture has a mixed image partly due to the time of its birth (agriculture would never have gotten off the ground if started in the twentieth century!), partly due to the learning curve and partly due to sheer misinformation. For example, scientific focus on the minute levels of chemicals arising from marine contaminants despite their being generally well within legal levels, to my mind, unfairly undermines the aquaculture industry and misses the main point, which relates to consumer health.

As incomes grow, expenditure on meat grows rapidly – and on fish even more so – due to high income elasticity of demand for livestock products. So with higher disposable incomes and urbanization, people move away from relatively monotonous diets of varying nutritional quality (e.g. indigenous grains or roots) towards more preprocessed food, more foods of animal origin, more added sugar and fat etc. This is accompanied by reduced physical activity leading to a rapid increase in overweight and obesity. Worldwide, the number of overweight people (about 1 billion) has now surpassed the number of undernourished people (about 800 million) and the World Health Organization (WHO) estimate there are 300 million obese adults and 115

FIGURE 7
Omega 3's, PCB's and mercury in fish and meat



Harvard Medical School 2007 : Harvard Heart Letter February 2007

million suffering from obesity-related conditions in the developing world (see FAO 2006b). This is leading to a growing interest in healthy eating.

Figure 7 helps to explain why an important part of the solution to this problem lies in greater fish consumption. Saturated and omega-6 fats mean poultry and red meat are a mixed blessing, whereas fish (especially marine fish) are very much a 'Good News' story due to their containing high levels of long chain omega-3 fatty acids (EPA & DHA) with well attested benefits to the cardiovascular system. Referring to the epidemic in diabetes and consumption of junk food, Wout Dekker of Nutreco has recently described fish as "living swimming functional food". Increasingly demographics favour older rich consumers wanting lean high protein, easily digestible food that helps them to live longer.

But for fish to take market share from land animals, it needs both the organization of supply chains and changes in consumer preferences. This message of fish health is not being sufficiently coordinated and promoted globally to consumers. At the same time, aquaculture must take care to maintain its healthy image, avoid contaminant scares, ensure sufficiently high levels of these long chain omega-3 oils remain in its products for consumer health purposes and avoid excessive substitution with vegetable oil feed ingredients.

CONCLUSIONS

Aquaculture is replicating the development steps seen in intensive livestock production, albeit at a much faster pace. This mirrors the focus on intensive production and industrialization with the resulting characteristics of commoditization, concentration, scale, price cycles etc. The immense diversity of aquaculture offers many mainline and niche products. But seafood distribution is fragmented compared with meat supply, and industry restructuring will occur. In this connection, there are large supply-demand gaps that need closing (e.g. 90 percent of United States seafood is imported). As with intensive land animal production, there is an ever-present threat of food scares due to quality and safety errors. This can wipe out a whole industry overnight and is linked to the question of biosecurity controls, not just on the farm but also along the value chain and at government level.

We have seen how closely breeding, genetics and health management are interlinked and hugely important in poultry production; this competence gap will constrain aquaculture without stronger public and private investment. However, aquaculture has the great advantage over red meat and poultry production of enhancing health and well-being, and the benefits of greater fish consumption need to be exploited more vigorously.

FIGURE 8
SWOT of aquaculture

STRENGTHS Long chain Omega3 content Unsatisfied demand/static wild catch	**WEAKNESSES** Genetics/selective breeding Less controllable environment
OPPORTUNITIES Promoting healthy image Species diversity/product range	**THREATS** Effect of food scares Bio-security breakdown

The implications of these concluding points are summarized (Figure 8) in the form of a 'SWOT' analysis of aquaculture's strengths, weaknesses, opportunities and threats.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Dr Ken Laughlin, Aviagen (who supplied Figures 4 and 5); Dr Eric Miller; Dr Leo den Hartog; Kontali (Figure 2); Prof Ragnar Tveterås (Figure 3); BioMar Group (Figure 6); Harvard University (Figure 7) and Dr Andrew Jackson of the International Fishmeal and Fish Oil Organisation (IFFO).

REFERENCES

Aasgaard, T & Austreng, E. 1995. Optimal utilisation of marine proteins and lipids for human interest. *In* H. Reinertsen & H. Haaland, eds. *Sustainable fish farming*. pp. 79–87. Rotterdam, Balkema.

FAO. 2006a. *The state of world fisheries and aquaculture*. Rome, FAO.

FAO. 2006b. *Livestock's long shadow: environmental issues and options*. Rome, FAO.

Gjedrem, T. 1997. Selective breeding to improve aquaculture production. *World Aquaculture*, 28: 33–45.

Havenstein, G.B., Ferket, P.R. & Qureshi, M.A. 2003. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poult. Sci.*, 82: 1500—508.

Laughlin, K. 2007. *The evolution of genetics, breeding and management.* Temperton Fellowship Report No. 15. Harper Adams University College. (In press).

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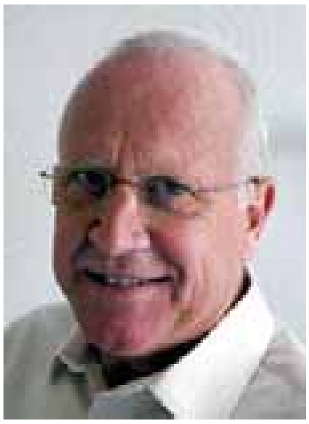

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The blue revolution – feed alternatives for aquaculture

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ABSTRACT

Rapid growth in aquaculture has led to a drastic rise in demand for feed. It is becoming increasingly apparent that because the traditional raw materials for feed production (fishmeal and fish oil) are limited, this is going to curb growth and slow down further developments. How can the aquaculture industry get around the "fishmeal trap"? The search for alternative feed resources is showing the first signs of success. A number of agricultural products, in particular, seem well suited to at least partially replacing fishmeal and fish oil. There has been remarkable progress in the development of weaning feed that could replace complicated live feed regimes for young fish and shrimp larvae. It is still not possible to do fully without rotifers and *Artemia* nauplii, but the day is drawing nearer when a starter feed will be available that can be given from the first day. This would make the farming of a lot of marine fish species, in particular, easier and give mariculture an important growth impulse.

INTRODUCTION

Aquaculture is developing and expanding in many countries throughout the world. The industry is diversifying and new species are coming up. This exciting development calls for renewal or at least slight modification of well-tried systems and practices. Consumers worldwide are paying attention to sustainability and environmental aspects of farming processes. Animal welfare on farms is a hot topic today. Society expects aquaculture to treat the fish with care and respect. If modern aquaculture is to retain its license to operate from society, it must meet the public's expectations and show itself to be a responsible industry. That requires, at least partly, new farming methods and improved technologies. This need for adaptation and renewal makes aquaculture a truly innovation engine.

One of the biggest problems is aquaculture's high dependence on fishmeal and fish oil for feed production. Demand for high-quality, suitable feed is growing, and the question as to how fishmeal and fish oil, which are both of limited supply, can be replaced is becoming increasingly urgent. The search for alternatives is one of the most important preconditions for the future growth of aquaculture. Carnivorous species like salmon and shrimp are aquaculture's main consumers of fishmeal and oil. Both give the best production results when they are fed high-quality fishmeal with minor additions of other protein sources.

Farming fish in aquaculture requires balanced feeds that supply them with all the nutrients they require. The choice of raw materials influences both the fishes' growth and health and also the flesh quality and flavour. In order to grow optimally, fish need certain amounts of proteins and, although the quantity required varies from species to species, it is usually over 30 percent even in the case of omnivorous species such as catfish. In such cases, however, it is possible to satisfy protein requirements almost completely with plant raw materials, for example, soybeans. Carnivorous species such as salmon and other salmonids also have few special demands as regards the origin of the raw materials – as long as the feed contains ten essential amino acids (arginine, histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine) in a good balance plus fatty acids, minerals, vitamins and pigments. (Amino acids that cannot be synthesized in animal bodies are classified as "essential.") Here lies an important chance for the feed industry, in that basically other raw materials can replace fishmeal in fish feed as long as they fulfil the special dietary requirements of the fishes!

RISING FISHMEAL PRICES INCREASE THE PRESSURE

Although the big breakthrough has still not come in the quest for alternatives for fishmeal and fish oil, fishmeal can already be replaced in part in salmonid diets by plant protein sources – usually wheat, soy meal or corn gluten meal. This is not without forfeiting protein digestibility and absorption of amino acids, however. Optimized mixtures in which plant raw materials are mixed into the feed or sometimes even "pre-digested" achieve better results, but even these often do not come up to those obtained with high-quality fishmeal. While digestibility of proteins in fishmeal is over 95 percent, it varies between 75 and 96 percent in the case of plant proteins, depending on the plant species. Added to this is the fact that fish are often less willing to eat the feed when it contains a proportion of plant raw materials. Presumably it is the different content of glutamine acid (which influences flavour) that is responsible for this. Against this background, it can be viewed as a considerable success that the industry has succeeded in reducing the share of fishmeal in salmon feed from 50 to 30 percent by replacing it with plant protein sources.

The pressure exerted on feed producers is increasing because fishmeal and fish oil prices on the world market are rising. Prices of about US$ 1 000 per tonne of fishmeal are forcing feed costs up and could become an obstacle to the growth of aquaculture. An even greater problem is the supply of fish oil. Lipid digestibility, feed utilization and the quality of the produced fishes are strongly dependent on the fat content and fatty acid profile of the fish feed. Both mono- and poly-unsaturated fatty acids (PUFAs) are important for fish growth and health. Feed producers are trying to use plant oils to partially replace fish oils with a high share of PUFAs. The suitability of plant oils with a high content of monoenes and less n-3 fatty acids is also being examined. Experiments are also being carried out with rapeseed and other plant oils – which are often, however, even more expensive than fish oil. In order to limit feed prices, completely new feed formulas will thus have to be developed. The requirements are extremely high: the new feeds have to fully satisfy the fishes' nutritional needs and must not change the health value and flavour of the final product.

Meals from marine products like krill, crabs or shrimp would also serve as alternatives to fishmeal in salmon and trout feed. Crab meal would have the advantage that it already contains the pigment astaxanthin that gives the salmon flesh its red colouring. The disadvantages of such meals, however, are that they rarely contain more than 50 percent protein and that they are only available in small quantities, usually as waste products in the processing industry.

Other animal proteins from meat, bone and blood meals would be conceivable as alternatives to fishmeal. They are inexpensive and rich in amino acids, but their digestibility and nutritional value vary considerably. About one quarter of the fishmeal in feed could be replaced, for example, by meat and bone meals (higher proportions can lead to growth depressions). However, these animal proteins are hardly freely available on the market because they are almost fully used up in the production of animal and pet feeds.

AMINO ACID SPECTRUM OF PLANT PROTEINS OFTEN INSUFFICIENT

Plant-based proteins are usually not as digestible as fishmeal. Their inclusion in the diet often results in depressed growth rates and feed intake. The main plant alternatives to fishmeal are oil seeds and cereals, which are produced worldwide in large quantities. Although the raw protein content of oil seeds (about 30 percent) is below that of fishmeal (about 65 percent), the amino acid spectrum is largely in accordance with a fish's nutritional requirements. Hopes are particularly high in soybean products, but sunflowers and lupines are also interesting. Cereal products are attractive as regards price but their raw protein content (12 to 15 percent) is considerably lower, which makes usage difficult.

Soybean meal (SBM), in particular, is currently seen to be a very promising alternative. By mixing in a SBM share, it would be possible to reduce the price of fish feed by a third, perhaps even by half. Soy grows quickly and is available in large quantities. The amino acid spectrum of SBM is, however, less suited to a fish's diet than that of fishmeal. Soybeans are a good source of lysine and tryptophan but contain a relatively small amount of methionine and cysteine. Added to this is the fact that soybeans contain some antinutritional factors. Antinutritional factors are compounds that influence nutrient digestion, uptake or other metabolic activities, and they can also even be toxic. For example, a naturally occurring antinutritional factor in uncooked soybeans is the Kunitz trypsin inhibitor that prevents the enzyme trypsin from breaking down dietary proteins in animals' intestines. For this reason, the soy share in fish feed should not exceed a certain level. If the share is too high, the fish react with reduced growth and weakened immune defence, sometimes even leading to serious health problems. While some carnivorous species can tolerate 20 percent soybean meal replacement, most fish can handle only 10–15 percent.

Pulses like peas that have a raw protein content of 22 percent would also be a possible alternative. Peas also contain antinutritional factors, however, that make their usage difficult. On the other hand, peas can be processed to protein concentrates (protein content over 50 percent) that are more easily digestible – but also more expensive. Apart from that, there is also the problem that the amino acid profile of grain and other plant concentrates does not correspond fully to a fish's needs, particularly as regards the essential amino acids methionine and lysine that are lacking in these products. Corn meal contains sufficient methionine and could replace 25 to 40 percent of the fishmeal, but it gives the fish fillet a yellow colouring that makes marketing more difficult.

Despite extensive efforts, scientists have so far been unable to replace more than 40 percent of fishmeal. A perfect alternative to fishmeal has yet to be found. Other possible protein substitutes have turned out to be in short supply, impractical or even the cause of nutritional problems.

FISH OIL ALREADY PARTIALLY SUBSTITUTED BY VEGETABLE FATS

The search for alternatives for fish oil is even harder. Apart from plant oils, some marine oils such as krill oil come into consideration. Krill oil is particularly rich in omega-3 fatty acids. The available quantities are low, however, and apart from that, krill oil is expensive. The price level is about the same as that of fish oil…so that really only leaves plant oils but – compared to fish oil – their share of the important fatty acids EPA and DHA is often too low. Researchers have already highlighted the possibility of using plant oils during the fishes' growing phase and only using fish oil in the last farming phase to re-establish the natural composition of human health promoting omega-3 fatty acids in fish flesh. At least in salmonids, a substitution of plant oils to levels of 50 percent will generally not result in growth reductions or increased mortalities.

WEANING FEED AND GREEN WATER TECHNIQUE

Another significant problem that aquaculture has to solve is the development of weaning feeds to simplify offspring production. Today, live foods such as rotifers or *Artemia* are used for rearing fish and shrimp larvae. While suitable starter feeds have long been available for young salmonids, cod, halibut and turbot larvae still have to be fed initially on live feed. Live feeds are costly, variable in quality and constitute a potential source of disease contamination. A weaning feed to replace live feed organisms would therefore be an important contribution to accelerate the further development of aquaculture. A formulated larval feed would mean less work for larvae producers, would be easier to use and would result in lower costs for larvae production.

The nutritional demands of marine fish larvae can currently only be met by live feed. The demands placed on weaning feeds are extremely high. Firstly, like any artificial diet, weaning feeds have to deliver a balanced nutrient profile in a cost-effective and biosecure manner. Secondly, the nutrients must be highly digestible in order to safeguard an adequate supply of larvae. Thirdly, the weaning diet also needs to be palatable and must be offered attractively to the larvae in order to ensure a good uptake of the feed particles.

In order to raise larvae of marine coldwater species like cod and halibut or warmwater species like seabass, dorade, sole and turbot, single-cell marine microalgae, rotifers (often *Brachionus plicatilis*) and *Artemia* nauplii have to be cultivated at the same time. In a lot of hatcheries that have specialized in the breeding of marine fish species, the fish channels and tanks only account for about half of the building area. The other half is reserved for departments in which the necessary live feed – algae, rotifers, *Artemia*, etc. – are produced. In spite of this effort, live feed only rarely really fulfils the demands of the larvae. For example, it is relatively lacking in nutrients or does not supply them in the required quantities. A simple tried and tested method of correcting this lack is to enrich the rotifers and nauplii with the missing substances, e.g. HUFAs (highly unsaturated fatty acids), amino acids or vitamins.

Progress has been made in the farming of marine fish larvae in the form of the green water technique, which basically involves enriching the water with algae. While this kind of green water was previously only used for feeding rotifers, it is today added to the water in which the fish larvae are contained. Scientific findings indicate that these microalgae have numerous positive effects. They are said to have an antibacterial effect, for example. Some polysaccharides that are contained in the cell walls of the algae stimulate the larvae's immune systems. Apart from that, the algae function as a biological filter because they remove potentially dangerous nitrogenous compounds from the water and produce oxygen to make up. Because they dim and diffuse the light, they enable homogeneous living conditions within the tank so that the larvae are distributed evenly throughout the water column. Due to their limited vision in green water, the larvae are also less diverted from their search for food: their prey stands out more against the murky background and they are more successful in picking out their food. It is also assumed that algae encourage the production of certain digestive enzymes and vitalize the larvae.

The mortality of marine fish larvae reaches its highest when the fish are taken off live feed and put onto dry feed. How strongly mortality rises depends on a large number of factors, including the quality of the dry feed that is given during this phase. It has to suit the larvae's requirements in size and composition and has to be sufficiently attractive to make sure it is chosen over live feed. Although it will presumably still be some time before a weaning feed that can completely replace live feed comes onto the market, the progress made so far is encouraging. Step by step, researchers are bringing forward the point at which fish larvae are given dry feed for the first time.

DEMANDS ON WEANING FEED ARE EXTREMELY HIGH

One of the problems is the size of the feed particles. The particles of the finest weaning feed are hardly bigger than the diameter of a hair. Despite this, their nutritional value has to be as similar as possible to that of live natural feed. Every feed granule has to contain everything the fish needs for its development: high-quality proteins with essential amino acids in a balanced ratio, carbohydrates and fats that are rich in poly-unsaturated fatty acids… plus micronutrients, minerals, vitamins and trace elements, and all of it has to be in a highly digestible form. Some ingredients are present in the feed particles in such inconceivably small quantities that we are almost talking about individual molecules. Added to this is the fact that some substances are soluble in water and have to be specially protected so that they really do get into the alimentary canal of the fish and are not lost in the water. Apart from that, the microfeed has to taste good too, if the larvae are to eat it at all, and it has to be soft so that it does not injure their delicate intestines. Digestibility can be controlled through the use of "native" proteins and the inclusion of hydrolyzed proteins such as peptides and free amino acids. Another challenge in replacing live feed has been the difference in feeding styles. While fish larvae swallow whole feed particles, crustaceans chew their food. This means that every feed particle – and they often have a diameter of only 50 µm – must contain all the necessary nutrients that the crustacean larvae need to grow.

HIGH-TECH FEED PRODUCTION

Already these few examples make it easy to guess that this kind of feed cannot be produced using conventional methods. Completely new techniques had to be developed. Two of the most important are microencapsulation and agglomeration. In general, two factors are the key to larval feed quality: leaching and digestibility. Leaching can be controlled by encapsulation of particles smaller than 300 µm and by coating particles larger than 300 µm.

Microencapsulation is a modern technique in which tiny quantities of substances are surrounded by a protective coating and at the same time enclosed in a microcapsule. This, on the one hand, serves to keep feed components together in the desired ratio and on the other hand, to protect water-soluble components and bind them in the feed particle. Various methods can be used for microencapsulation. For example, the feed components can be enclosed in tiny fat droplets or sprayed with microscopically fine lipid pearls that form a kind of net around the granule. It is also possible to make coatings of gelatine or protein. For the production of a protein coating, a polypeptide thread is wrapped around the feed granule like a strand of wool. Because the molecular building blocks of this thread then form cross-links, a stable coating is produced that on the one hand has a high nutritional value and is itself digestible and on the other hand has gaps that enable the digestive enzymes in the fish larvae's intestine to make a direct attack on the substances inside the feed particle.

Agglomeration really means accumulation and comes from the Latin word "agglomerare", to connect firmly. It is a special principle in which tiny microparticles practically "voluntarily" form larger particles. More and more particles connect up with a relatively coarse structure so that the construction gradually becomes larger. This process is called coalescing or in pharmacy, wet granulation. Agglomeration is currently the only technique for producing water-stable feed particles in the micro range. In contrast to traditional techniques that are all destructive (large feed particles are broken down through grinding), agglomeration is a constructive process in which the particles are built up as required. It is important that the agglomeration process takes place without the impact of heat that could damage the microcapsules and denaturalize individual feed components, i.e. reduce their nutritional value. At its most simple, agglomeration can be achieved by slightly moistening a powdery substance and then drying it again. The powder-fine particles clump together and form a kind of granulate.

Homogeneous feed particles in the range of 250-700 µm are produced in a particle agglomeration device called a "marumerizer". "Micro-extrusion marumerization" represents a remarkable progress in microfeed technology. The technology can also be used to apply liquid or powder coatings to the particles.

The feed particles produced using agglomeration (also called clusters) look like tiny raspberries when viewed using a microscope. This structure has the advantage that tiny air bubbles remain between the feed globules that reduce the specific weight of the mini feed granules. They float in the water or sink very slowly to the bottom, so that the larvae have sufficient time to pick them up. The longer a particle floats in the water the more likely it is that the larvae will mistake it for rotifers or nauplii and eat it.

Although so far no feed producer has succeeded in fully replacing rotifers, *Artemia* nauplii or other live feed for farming marine fish larvae, the phase of live feeding is constantly being shortened by high-quality dry feed, and feeding regimes are becoming more economical.

CONSUMER RESERVATIONS PREVENT GENETIC MANIPULATION SOLUTIONS

One of the conceivable options for at least partially solving the feed problem in aquaculture and escaping the fishmeal trap would be genetic manipulation. In general, transgenic technology has the potential to enhance fish production to meet the rising demand for fish and could also have other benefits for humans. Strictly speaking, genetic techniques could even approach the problem from two sides at the same time. On the one hand, via modification of the produced species so that they take up and utilize feed that they could not do previously, and on the other hand, via genetic influencing of the feed raw materials, for example by adapting the fatty acid spectrum or amino acid composition of agricultural products more strongly to the requirements of the fish.

A lot of the plants that are produced using agricultural methods are already in some way genetically manipulated, usually through selective farming. A simple method: from generation to generation only the largest, best or those that are the most useful for a particular purpose are selected. These are then used as the next generation of parents. However, so called genetic engineering or gene technology has nothing to do with conventional breeding and selection. Its basis is a transfer of genes from one organism to the gene set of another, even unrelated, organism. The foreign DNA is inserted into the nucleus so that it participates in chromosomal replication and becomes part of the hereditary material of the cell. This results in quite new varieties of organisms. Primarily, targets for genetic manipulation could be faster growth, better feed conversion and improved disease resistance, but the technology can also be used to insert additional beneficial genes that would provide stress resistance, hypo-allergens and enhance taste, colour, reproduction and sex change.

However, transgenic fish has unknown biological properties, and gene expression does not always alter performance. The mechanisms that control genome expression are so complex that some of the biological effects cannot be predicted with certainty. That is one of the main reasons why consumers reject and thereby prevent the use of this technology. It is feared that transgenic fish might pose some serious risks, including threats to ecological integrity and biodiversity. Transgenic fish could escape and become part of the gene pool of wild fish populations. This could add genetic diversity to the population, lower or raise fitness, or have no recognizable effect (some of the possible effects might be temporary, because transgenes are – like any other genetic material – the object of natural selection processes). Therefore before the production of any transgenic fish is initiated, their possible impact on the ecosystem and environment must be studied very carefully.

Transgenic technology has been controversial, as it is a new concept and poorly understood. Lack of information on the potential ecological and socio-economic impacts of transgenic fish has contributed to a growing debate on biosafety problems of transgenic fish.