AQUACULTURE – SALVATION OF COD IN NORTH ATLANTIC FISHERIES?

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ABSTRACT

Over the last decades fish resources have declined to a minimum. Although fisheries management systems tried to limit the natural resource access, overfishing is still an ongoing topic. To conserve fish stocks, the alternative of culturing the fish has been experiencing an upswing.

The case of cod plays a decisive role in fish farming as it is one of the main commercial fish which is overexploited. Because of the high demand there is a need to stabilize and ensure the cod fishery for future benefit.

This paper deals with the progress of aquaculture since the early 1970s related to the conservation of the demersal fish cod in the North Atlantic fisheries. The central questions are: Which effects did build up aquacultures and have impact on the development of cod fisheries?

Did aquaculture constitute a useful addition to recovery plans of cod stocks? What were the socio-economic consequences of fish farming?

In fact, the aquaculture of cod cannot substitute the fishing sector (yet or in the coming future). It is linked with employment creation on the one side but fishermen will still have to generate their own proceeds on the other. From the biological point of view special and costly conditions are required to culture cod. The demersal fish is only able to survive in cold waters and therefore linked to designated regions. Species appropriate for cultivation is not easy to achieve.

It is a debatable point whether aquaculture can make a contribution to conserve the natural resource cod.

INTRODUCTION

Cod fisheries are characterized by overexploitation and decreasing catch amounts on the one side and an increasing demand of white fish for human consumption on the other. Fisheries management enacted several measures concerning the conservation of stocks for future harvesting. But these could not stem overfishing. Besides restrictions of fishing effort for capture production, it has to be questioned if aquaculture production could be a meaningful addition to satisfying the market demand for cod and rebuilding the depleted stocks.

The following paper investigates the progress of cod aquaculture and discusses conditions that have to be met for its successful expansion with respect to the sustainability approach. It gives a general overview and does not reflect detailed aspects of cost-benefit analyses concerning feeding or environmental costs. It focuses on the exploration if cod farming can make a useful contribution to conserve cod to solve supply problems.

THE CURRENT STATE OF AQUACULTURE PRODUCTION OF COD

Almost seventy-five percent of the world's commercial fish stocks are reduced to a non-sustainable level[1]. But the demand for fish is increasing. According to the Food and Agriculture Organization FAO, the worldwide fish consumption has risen from 9.0 kg per capita in 1961 to approximately 16.6 kg in 2004[2].

In general, scientists agree about the fact that the demand can only be met by farming the fish species required. According to Nai-Hsien Chao and Chiu I. Liao "[...] aquaculture is considered to be the production mechanism that will provide fishing products that capture fisheries can no longer provide".[3] Holmer et al. also state that "[it] will be impossible in the future to maintain wild captures at the level of consumer demand"[4]. Indeed, the world fishery production from aquaculture has increased during the last four decades. Whereas in 1978, about ten percent of the total world fishery production came from aquaculture[5] in 2007, the estimated share was thirty percent[6]. The average contribution of aquaculture to per capita fish supply for the world excluding China had risen from 13.7 percent in 1994 to approximately 21.4 percent in 2004. This equates to an expanding growth in per capita supply from 1.8 kg in 1994 to 2.9 kg in 2004[7].

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[1] Jorge Cirske, "Review of the State of World Marine Fishery Resources", *FAO Fisheries Technical Paper 457* (Rome, 2005), 8.
[2] Food and Agriculture Organization of the United Nations (FAO), "The State of World Fisheries and Aquaculture 2006" (Rome, 2007), 36.
[3] Nai-Hsien Chao and Chiu I. Liao, "Sustainable Approaches for Aquaculture Development: Looking ahead through Lessons in the Past", 73, in Theresa M. Bert (Ed.), *Ecological and Genetic Implications of Aquaculture Activities*, (Dordrecht, 2007), 73-82.
[4] Marianne Holmer/ Kenny Black/ Carlos M. Duarte/ Nuria Marbá/ Ioannis Karakassis (Eds.), *Aquaculture in the Ecosystem*, (Dordrecht, 2008), v.
[5] Frederick, W. Bell, *Food from the Sea: The Economics and Politics of Ocean Fisheries*, (Boulder/Colorado, 1978), 275.
[6] Nai-Hsien Chao and Chiu I. Liao, "Sustainable Approaches for Aquaculture Development", 74.
[7] Food and Agriculture Organization of the United Nations (FAO), "The State of World Fisheries and Aquaculture 2006" (Rome, 2007), 38.

Overall, aquaculture industry continues to grow most rapidly compared with all other animal food-producing sectors. Since 1970, the average annual growth rate for the world represents 8.8 percent per year while capture fisheries constitute only 1.2 percent and terrestrial farmed meat production systems 2.8 percent[8].

The FAO has listed the top ten species groups in aquaculture production that include e.g. carps, salmons, trouts or tilapias. Channel catfish and both, Atlantic and Pacific salmon, dominate the aquaculture sector in the USA and Canada. Salmonids head the list in Latin America and the Caribbean[9]. But Atlantic cod is not reported in the top ten list in 2004, although it belongs to endangered species that attaches special importance in fisheries management.

Since the sixteenth century cod or *gadus morhua* had been the main species harvested in North Atlantic fisheries. Cod was exploited by Britain, France and Portugal. This species can grow to a large size, reaching a maximum of over 100 kg and 2 metres. It offers a high value in food and price[10].

But according to studies of the Food and Agriculture Organization (FAO), catches of Atlantic Cod have declined dramatically between the 1960s and the 1990s as shown in figure 1. Capture production in the Northwest Atlantic attaches special importance as catches of cod had been reduced to a minimum. Cod stocks had been suffering from overexploitation and fisheries management had to impose fishing bans for cod fisheries on the Grand Banks in the early 1990s[11]. Also in fishing areas of the North Sea, Eastern Channel and Skagerrak, cod belongs to the endangered species. Following figure illustrates the global total catch of cod between 1950 and 2004.

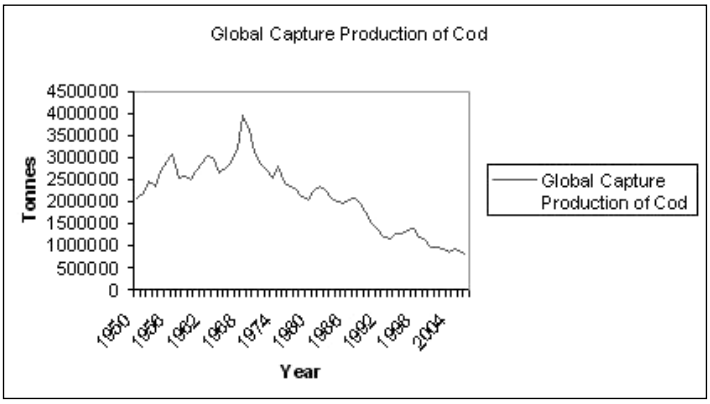

Fig. 1. Global Capture Production of Cod

Source: Food and Agriculture Organization of the United Nations (FAO), Species Fact Sheets gadus morhua.

[8] Ibid., 5.
[9] Ibid., 17, 20.
[10] T.V.R. Pillay/ M. N. Kutty, *Aquaculture. Principles and Practices*, 2nd Ed., (Oxford, 2005), 463.
[11] International Council for the Exploration of the Sea (ICES), "Spawning and Life History Information for North Atlantic Cod Stocks", *ICES Cooperative Research Report,* No. 274 (June 2005), 115.

Catches of Atlantic cod decreased in total from nearly 4 million tonnes in 1968 to 890,000 tonnes in 2002 following a downtrend. In 2005, the worldwide catch of Atlantic cod counted 843,739 tonnes[12]. Therefore, the need for enhancing production through artificial breeding was highly encouraged corresponding to the declining supply through capture production[13].

Figure 2 depicts the global aquaculture production for *gadus morhua* between 1950 and 2006.

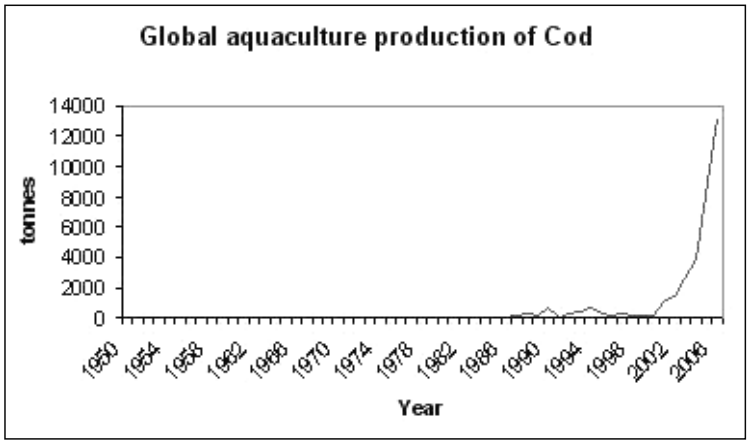

Fig. 2. Global Aquaculture Production of Cod

Source: Food and Agriculture Organization of the United Nations (FAO), Species Fact Sheets gadus morhua.

Although attempts to farm cod had been made before the 1980s, significant artificial cod production did not show up in the statistics before the mid-1980s. Since the early 2000s, the global aquaculture production of cod has been growing noticeably[14]. In 2005, farmed Atlantic cod increased to 8,121 tonnes of market-sized fish. But in comparison to the quantity caught in the wild, this is only a marginal contribution to cod supply[15]. A closer look to the history of cod farming should explain the reasons of this slight development.

[12] Food and Agriculture Organization of the United Nations (FAO), Species Fact Sheets Gadus Morhua http://www.fao.org/fishery/species/2218, accessed 19.05.2008.
[13] T.V.R. Pillay/ M. N. Kutty, *Aquaculture. Principles and Practices*, 2nd Ed., (Oxford, 2005), 463.
[14] Food and Agriculture Organization of the United Nations (FAO), Species Fact Sheets Gadus Morhua http://www.fao.org/fishery/species/2218, accessed 19.05.2008.
[15] Anna K. Sonesson/ Bendik Fyhn Terjesen/ Barbara Grisdale-Helland/ Turid Mørkøre/ Morten Rye/ Terje Refstie/ Igor Babiak/ Kjersti Fjalestad, Anne Kettunen/ Bredan McAndrew, "Atlantic Cod (Gadus morhua)", *Review on Breeding and Reproduction of European aquaculture species* (January 2008), 2.

THE HISTORY OF COD FARMING

Aquaculture originated under different social and economic conditions in various parts of the world. It is based on a long history of finfish and shellfish culture in Asia, ancient Egypt and central Europe[16]. Commercial fish culture of carp is first described in ancient Chinese manuscripts, as mentioned in the publication *Classic of Fish Culture* around 500 BC. According to this document, carp was cultured in rice patties. Ancient Hawaiians furthered these methods and built pens for breeding carp and tilapia. Since these times aquaculture has been vastly improved and was introduced to Europe from the Middle Ages[17]. The culturing of oysters dates back to the Roman times[18].

There are different ways of farming fish. The distinction can broadly be drawn between extensive systems, intensive systems and stocking of wild populations or sea-ranching systems. Extensive aquaculture describes habitats that are established in the ocean, lakes, or fjords which contain mesh enclosures with fish. Extensive aquaculture systems need less effort put in the husbandry of fish than intensive aquaculture. Its successful outcome is highly dependent on the natural environment of the habitat. Extensive systems are often used for the production of lower-value freshwater finfish such as cyprinids targeting the domestic market[19].

Fish in intensive hatchery systems live in artificial habitats such as tanks and raceways. Support parameters are carefully controlled by strategic management. "Intensive juvenile production is based on the control of all aspects of production, including water exchange, light, density of both cod and feed organisms, the quantity and quality of feed organisms, and hygiene and health conditions"[20]. The intensive system is linked to high operating costs but as well to high yields per unit area. Intensive systems are suitable for high-value species such as salmonids, marine finfish or molluscs targeted towards luxury or niche markets[21]. Cod can be produced both by extensive and semi-intensive systems.

Some techniques of both systems can be adapted for stocking selected species or enlarging existing populations, in terms of sea-ranching[22], through the release of

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[16] Bell, *Food from the Sea*, 275/279.

[17] Pillay and Kutty, *Aquaculture,* 7–9. See also Adrian Nelson, "Aquaculture", http://biology.kenyon.edu /stures/Compsnelson/Aquaculturepage.htm (accessed 18.06.2008)

[18] Bell, *Food from the Sea,* 275.

[19] Elvira Bayulut. "Aquaculture Systems and Practices: a Selected Review". Food and Agriculture Organization of the United Nations. Rome, 1989, as cited in Adrian Nelson, "Aquaculture", http://biology.kenyon. edu/stures /Compsnelson/Aquaculturepage.htm (accessed 18.06.2008)

[20] T. Svåsand/ H.M. Otterå/ G.L. Taranger, "The Status and Perspectives for the Species", in E. Moksness/ E.Kjørsvik / Y.Olsen (Ed.), *Culture of Cold-Water Marine Fish* (Oxford 2004), 436.

[21] Adrian Nelson, "Aquaculture", http://biology.kenyon.edu/stures/Compsnelson/Aquaculturepage. htm (accessed 18.06.2008).

[22] According to M.N. Kutty and T.V.R. Pillay, 'the term ranching is used here only when a species is allowed to forage around freely in extensive waters like areas in the sea, and is able to return to its home waters at a certain stage of its life'. T.V.R. Pillay and M.N. Kutty, *Aquaculture*, 594.

juvenile cod in open waters. “The main advantage in both, stocking and ranching is the elimination of the controlled grow-out phase and consequent savings on artificial feeding and stock maintenance, besides the capital costs of grow-out facilities”[23]. The outcome of cod stocking will be explored later in this text.

First attempts at the artificial production of juvenile cod had been made in Norway at the Flødevigen Research station in 1884. Several thousand cod juveniles were produced in a 2500 m^3 basin with the purpose of testing the viability of millions of hatched larvae that had been released on the Norwegian Skagerrak coast. These experiments lasted between 1884 and 1971. In the USA and Canada, similar cultivation experiments were done with Atlantic cod. Hundreds of millions of newly hatched yolk-sac larvae were released annually to stock the sea but benefits were not documented during that time[24].

Norwegian scientists put new efforts in the development of breeding juvenile fish. Feeding, environmental conditions and production costs had to be taken into consideration. Finally, experiments in 1976 and 1977 showed new results in the feeding behaviour. Cod larvae in confinement accepted natural plankton and could have been produced with the same natural zooplankton as wild cod. As predators were removed, the survival rate of cultured cod had been improved. In 1983 researchers from the Austevoll Marine Research Station, Institute of Marine Research, managed to produce more than 70,000 t of small cod in a 60,000 m^3 sea-water enclosure. This was the start of “another cod period” in Norway. Many different production systems were built. As part of the sea-ranching activity, cod juveniles were also produced in Sweden, Denmark and the Faroe Islands.

Small-scale intensive and extensive production of Atlantic cod expanded during the 1980s both in Norway and the UK. But “although the quality of the juvenile cod produced by extensive and semi-intensive systems has been good, and comparable with that of wild cod [...], the production results have been too small and unpredictable to be commercially viable”[25]. Between 1990 and 1993 Norwegian companies, while consulting numerous research institutions, tried nevertheless to expand cod farming to a large-scale intensive production system. A high number of cod were produced, but problems such as cannibalism[26] led to a high mortality rate that damaged the number of produced fish. Finally, trials to expand the production ended in 1993. Cod did not appear to be an economically profitable aquaculture species[27].

[23] Ibid., 594.
[24] Svåsand et al., “The Status and Perspectives for the Species”, 433, 435.
[25] Ibid. 436.
[26] As cod is known as an omnivore, cannibalism occurred as a result of sub-optimal feeding and physical rearing conditions. (Svåsand et al., “The Status and Perspectives for the Species”, 436).
[27] Svåsand et al., “The Status and Perspectives for the Species”, 436.

But because of the continuous decrease in catch amounts of cod and increasing market prices for the species the interest in cod farming arouse again by the late 1990s. Both in the UK and Canada, as well as in Scotland, Newfoundland and Norway, hatcheries were built between 1999 and the early 2000s. By making use of production techniques from the intensive juvenile production of other species like sea bass or salmonids, it was possible to reduce costs and to put new efforts in the development of cod farming.

SUSTAINABLE AQUACULTURE PRODUCTION OF COD

Fisheries management is based on sustainability development. The definition is found in the Brundtland Report, published in 1987 by the World Commission on Environment and Development (WCED). "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[28]. The Fisheries Department of the FAO has published the Code of Conduct for Responsible Fisheries[29]. It transfers all aspects of sustainability to fisheries and aquaculture. Although it is a voluntary Code, some elements refer to relevant rules of international law. As stated in the Brundtland Report, sustainable development is dependent on objectives concerning environmental, economic and sociological factors.

Aquaculture also follows sustainable management criteria. The needs of biological factors – namely water quality, environment, fish biology –, sociological factors – such as employment, rural sociology, land tenure, or nutritional needs –, and economic factors – such as viability, comparison in cost/benefit terms with other technologies – have to be met by making decisions about investing in aquaculture production[30].

In the following all factors are briefly discussed concerning the aquaculture production of cod.

The major challenge of cod farming is to develop all methods best at a scale that is economically profitable. Engelsen et al. investigated economic aspects of new species in aquaculture. "The main goal for all participants in the aquaculture industry is profitability (or, alternatively, satisfying returns on the investment made)"[31].

[28] Brundtland Report, UN General Assembly Document A 42/427.
[29] Please see *FAO* (www, 2006), *Code of Conduct for Responsible Fisheries* for further information.
[30] Rowena M. Lawson, *Economics of Fisheries Development* (Connecticut, 1984), 252–256.
[31] R. Engelsen, F. Asche, F. Skjennum, G. Adoff, "New Species in Aquaculture: Some Basic Economic Aspects", in Moksness et al. (Eds.), *Culture of Cold-Water Marine Fish*, 487.

Figure 3 depicts the volume and prices of cod between 1989 and 2000. As illustrated, the fillet yield of farmed cod exceeded the fillet yield of wild fish[32]. Noticeably, cod farming can only be profitable if products can be sold at reasonable prices[33].

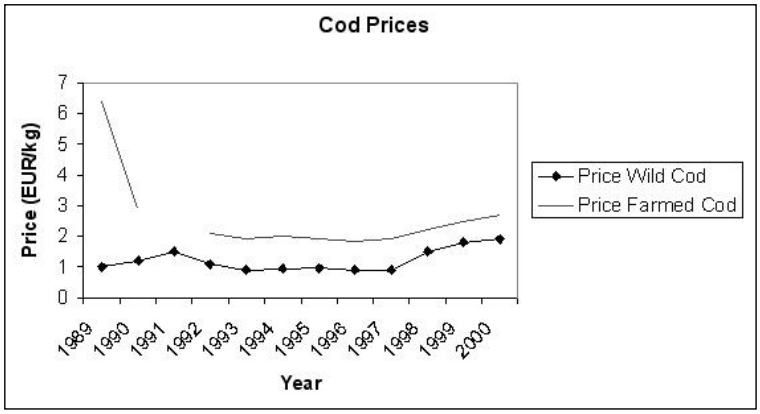

Fig. 3. Cod prices

Source: United States Department of Agriculture as cited in R. Engelsen, F. Asche, F. Skjennum, G. Adoff, "New Species in Aquaculture: Some Basic Economic Aspects", 487–516, E. Moksness, E. Kjørsvik, Y. Olsen (Eds.), Culture of Cold-Water Marine Fish (Oxford 2004), 499, modified.

The interest in cod farming increased in the last few decades due to improvements in technology, experiences made in the production of juveniles, the declining capture production, and an increasing market price for cod. But on the other side, farming was also labour-intensive and unpredictable, like in the early 1990s when cod farming did not represent a success. This is possibly due to the fact that wild stocks rebounded temporarily and market prices fell. As several companies tried to expand their production during this period, and produced a relatively high number of juveniles, the low market price could not compensate high production costs and financial losses followed[34].

Since the twenty-first century cod farming has been thriven. Prices increased and natural stocks have been suffering from overexploitation. "It is to establish farming at a suitable level of productivity to make the activities profitable"[35]. If technical improvements, such as the adaptation of the use of production techniques from other intensive juvenile production of other species, continue to reduce production costs, investments made in farming cod seem to become worthwhile in the future as long as then market price is suitable.

[32] Ibid. 499.
[33] Grethe Rosenlund and Magnus Skretting, "Worldwide Status and Perspective on Gadoid Culture", 197, *ICES Journal of Marine Science*, 63, 194–197 (2006). DOI:10.1016/j.ices.2005.11.012.
[34] Engelsen et al., "New Species in Aquaculture", 496/7
[35] Ibid. 497.

Farmed cod is likely to enter different market segments. On the one side, there could be a larger segment for cod products with low prices and a smaller segment for fresh cod of high quality achieving higher prices on the other. If production costs and all year round availability can be reached regularly, the consumption of farmed cod could compete with the consumption of the wild cod[36]. But the expansion of these market segments is dependent on the consumer behaviour and acceptance. Currently, farmed fish exhibits a negative image[37]. Therefore, marketing and presentation of farmed products are of major importance to be able to sell the farmed products at reasonable prices[38].

As Theresa M. Bert state, "social acceptance, reasonable economic gain, and adherence to relevant laws and regulations are necessary for the success of any industry. Regulatory entities and other stakeholders, together with aquaculture-industry leaders, need to continue their focus on expanding the industry in ways that are beneficial to people, compatible with the environment, and supportive of laws and regulations designed to protect biodiversity"[39].

Statistics of the FAO show that millions of people's income around the world depends on fisheries and aquaculture. "During the past three decades, the number of fishers and aquaculturists has grown faster than the world's population, and employment in the fisheries sector has grown faster than employment in traditional agriculture"[40]. As counted in 2004, one-quarter of fish workers were fish farmers. While the great majority of fishers and fish farmers can be found in developing countries, principally in Asia, the number of fishers in Norway declined significantly between 1970 and 2004. But the number of fish farmers and aquaculture activities increased in Norway and also expanded in many industrialized countries[41].

Countries with cod farms are mainly situated on the east coast of Canada and USA, in Norway, and the United Kingdom. In 2003, three hatcheries of cod could be found in Canada and the USA, two in the United Kingdom and one smaller hatchery in Iceland. About 16 hatcheries operate in Norway. While aquaculture production of cod was progressing slowly in Canada and North America, Norway turned out to lead the cod farming industry[42].

As the equipment used for the hatchery of salmon is also suitable for gadoids such as Atlantic cod, most cod hatcheries are found in the main areas of the salmon, sea bass, or seas bream farming industry. The adaptation of technical equipment from other

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[36] Olav Sigurd Kjesbu, Geir Lasse Taranger, Edward A. Trippel, "Gadoid Mariculture: Development and Future Challenges", *ICES, Journal of Marine Sciences 63*: 187–191 (2006), 190./ see also: Engelsen et al., 499.
[37] Kjesbu et al., "Gadoid Mariculture", 189.
[38] Lawson, *Economics of Fisheries Development*, 61.
[39] Theresa M. Bert, "Environmentally Responsible Aquaculture: Realities and Possibilities", 495, in Bert (Ed.) *Ecological and Genetic Implications of Aquaculture Activities*, 479-514.
[40] FAO, "The State of World Fisheries and Aquaculture 2006", 22.
[41] According to the FAO, the numbers of fishers in Norway exhibited a decrease of 54 percent (FAO, "The State of World Fisheries and Aquaculture 2006", 22).
[42] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 195.

farmed species facilitates the establishment of economical profitable aquaculture production of cod[43]. In this case, previous risk evaluations before introducing a new species allowed the application of existing rules, regulations and policies in cod farming industries. To foster socioeconomic and regulatory requirements concerning sustainable aquaculture, both, the establishment of environmental-protection laws and regulations, and the education of participants in the aquaculture industry should prevent environmental problems generated by poor aquaculture practices. Moreover, public recognition of good aquaculture production should help to improve markets for local farmed fish[44]. The expansion of cod aquaculture industry is likely to be done if aquaculturists comply with the requirements on the one side and if consumers accept the new species on the other.

The biological settings are most important for building up cod aquaculture production. This is due to the fact that profitability is dependent on the flesh quality of the fish. "Flesh quality is central to achieving acceptance and a suitable price for the farmed gadoids in the market"[45].

To obtain cod eggs for aquaculture, natural spawning is the most usual way[46]. Experiments showed that cod spawn naturally in confinement. There is only little effort needed to get large amounts of eggs and larvae of a high survival rate[47]. To reach market size of an anticipated weight of 3.0 kg till 4.5 kg, juvenile fish need twenty-four till twenty-eight months from hatchery[48]. Sustainable cod aquaculture production depends on a high survival level during the on-growing phase.

But some problems have occurred with breeding cod. Cod often reaches sexual maturation too early. The fish looses its body weight during the spawning season what extends the time to achieve the desired market size by at least four months. This increases the amount of feed needed to produce fish at the certain size[49]. The artificial accelerated growth impacts the liver of the farmed fish. From this follows a much larger energy deposition and a fatty liver which impairs the flesh quality. Although efforts have been put into feeding restrictions or the use of low-energy diets to diminish energy deposition, liver sizes could not have been reduced to those of wild populations[50].

Another challenge poses the larval quality. Many hatchery-reared juveniles exhibited deformities. This is mainly caused by inappropriate rearing conditions such as water current, gas super-saturation, or nutrition. Especially feed resources raise a problem because of the limited supplies of fishmeal and fish oil needed. As mentioned above, alternative sources such as marine zooplankton could be utilized. But long-term

[43] Ibid., 194.
[44] Bert, "Environmentally Responsible Aquaculture", 495–497.
[45] Kjesbu et al., "Gadoid Mariculture", 189.
[46] Svåsand et al., "The Status and Perspectives for the Species", 433.
[47] Pillay and Kutty, *Aquaculture,* 464.
[48] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 196.
[49] Ibid., 196.
[50] Svåsand et al., "The Status and Perspectives for the Species", 440–441.

studies about the gadoids' ability are still under examination. To reduce the cost of juveniles and to ensure sustainable and economically feasible aquaculture production of cod, also the environmental impacts of cod culture have to be issued. These include the genetic impact of escapes and spawning in cages on wild stocks, nutrient load, diseases or heavy metal to name some of them[51].

Detailed information concerning long-term studies about sustainable cod farming is still in development. Therefore research and development has to be further extended.

To summarize, there is high demand for the expansion of cod aquaculture with respect to extensive and intensive production systems. Otherwise, the production of farmed cod is connected with some problems of juvenile mortality, high production costs or a lack of consumer acceptance. All factors of sustainable development have to be considered to overcome the bottlenecks and to tap the full potential.

STOCKING OR SEA-RANCHING

Besides culturing cod in extensive or intensive systems, stocking of natural stocks have to be considered by questioning if farming cod can solve supply problems. As these techniques refer to aquaculture done in open waters, they bring some advantages. According to Kutty and Pillay, these are "the elimination of the controlled grow-out phase and consequent savings on artificial feeding and stock maintenance, besides the capital costs of grow-out facilities"[52].

As this method of aquaculture is under development as well, there exists only little experience in measuring the economic return on investments. In some cases an increase in the commercial catch amount was documented after a remarkable number of spawners from hatchery had been released. Different issues have to be considered for a successful release. The mortality rate of fish larvae and juveniles should be diminished[53]. Experiments done with genetically marked yolk-sac larvae demonstrated that the survival in natural environment is dependent on the size of fish. Therefore, before fish is released, it has to grow to an adequate size to be able to protect itself from predators[54].

The release of cod larvae in the Oslofjord in Norway was possibly the first large-scale attempt to stock the sea. But the attempt did not bring positive results and was stopped in 1971[55]. Release experiments were done between 1976 and 1995 in several Norwegian fjords and coastal waters. About one million tagged juvenile cod were

[51] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 196/197.
[52] Pillay and Kutty, *Aquaculture,* 594.
[53] Ibid., 594.
[54] T. Svåsand and E. Moksness, "Marine Stock Enhancement and Sea-Ranching", 475–485, in Moksness et al. (Eds.), *Culture of Cold-Water Marine Fish,* 477.
[55] Pillay and Kutty, *Aquaculture,* 600.

released to test whether stocking could enhance the number of wild stocks. A smaller number of Atlantic cod were freed as well in Denmark, the Faroe Islands, Sweden and the USA during the 1990s.

Although cultured juveniles seemed to adapt well to the natural environment, some differences to wild populations appeared. These were documented in higher mortality rates, different migration patterns and feeding behaviour. On the other hand, the genetic drift between wild and cultured cod did not pose a major problem as only few differences in genotype distribution and gene frequencies were examined. The recapture rates of the tagged released cod changed from 0–30%. This was due to changes in area, time and size at release. All in all, the experiments' results pointed out that releases of cod juveniles did neither significantly enlarge wild cod stocks nor the amount of cod catches[56].

CONCLUSION AND FUTURE TRENDS

This paper gave a short overview about the development and current state of Atlantic cod aquaculture in terms of confinement systems and stocking, and the main challenges both segments have to deal with concerning biological, economic and sociological factors. The question was raised whether aquaculture can save the wild cod from extinction by supplying the demand through farmed fish products. Whereas stocking the sea did not lead to the expected success, intensive and extensive production systems exhibit a high potential to make a contribution.

Between the 1980s and 1990s, great efforts were put into the expansion of cod farming. But commercialisation processes stopped as the expected results had not been reached. Instead, hatcheries techniques for other species such as sea bass, sea bream or salmon were intensified. "This production is fairly reliable and predictable, reflecting the higher level of competence and experience in marine larval rearing leading to good survival. The development of cod hatchery protocols has benefited from this experience"[57]. This was due to the opportunity of the adaptation of the same equipment used by other farming industries to cod farming. In consequence, the establishment of cod farms was made easier. In the early 2000s, cod farming exhibited an upswing. Due to declining natural wild stocks resulting in quota reductions, the demand for white fish increased and prices had been risen. National and international fish companies foster investments in cod farming, aiming at reducing production costs to a minimum[58].

[56] Svåsand and Moksness, "Marine Stock Enhancement", 477–479.
[57] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 196.
[58] Svåsand et al., "The Status and Perspectives for the Species", 442.

Several conditions have to be met to ensure a profitable and sustainable cod farming industry in the future. Besides biological factors such as juvenile mortality, flesh quality or growth enhancement and health, the labour-market situation and cost-benefit analyses have to be addressed.

Rosenlund and Skretting point out what makes cod farming a growing and flourishing sector. They emphasize the need of a changing structure of the farming industry from smaller companies towards fewer bigger and integrated companies. Previously, on-growners, processing, sales and marketing were not connected. To support a rapid development of cod farming and to stabilize production costs and prices, a linkage between these segments "allows the same company to have control over all parts of the value chain, from juvenile production to marketing of the processed fish"[59]. While this value chain approach should ensure a good flow of products to markets, in developing countries traditional smaller farming companies are often removed by bigger ones what can have negative effects for the sociological situation of traditional farm workers[60]. Therefore, different interests by major aquaculture companies should consider the benefits or needs for local people.

For the future, cod farming is planned to be expanded. The short-term production goal has been set by 10,000 tonnes of market-sized slaughtered cod per year. 1000–2000 tonnes were counted between 2003 and 2005. This amount still includes wild-caught undersized fish. In 2010 scientists expect a high increase in gadoid production. While cod production in Canada and the USA will support this sector marginally, Norway will be the leading country in cod farming. A strong support by government and investments made by private companies, and the use of similar technology to existing salmon farms sets ideal conditions for this country. Norwegians even established a national network "go for cod" aiming at creating an economically feasible cod aquaculture production. This network tightens the cooperation between cod farmers, scientists and the fishing industry[61]. According to Rosenlund and Skretting, "Norway will serve as an example of how the development of the cod farming industry may occur"[62].

Due to the fact that ICES has given a zero catch advice for coastal cod in subareas I and II for 2009[63] as a result of the low spawning stock biomass and recruitment, demand for cod flesh will have to be supplied by the alternative of cultured fish.

Meeting the conditions needed to create an efficient cod farming industry concerning all factors of sustainability seem currently to be most promising so that this species will possibly also be considered in the FAO's top ten list of farmed fish in the near future. But although high production rates are expected, it will take years to meet the

[59] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 196.
[60] Ibid., 196–197.
[61] Svåsand et al., "The Status and Perspectives for the Species", 442.
[62] Rosenlund and Skretting, "Worldwide Status and Perspective on Gadoid Culture", 195.
[63] ICES Advice 2008, Book 3, (Norwegian Coastal Cod (Subareas I+II), http://www.ices.dk/committe /acom/comwork/report/2008/2008/cod-coas.pdf, accessed 13.06.2008.

demand as the amount of produced cod is marginal in comparison to the catch amount. Moreover, production costs have to be reduced and consumer acceptance has to be improved to draw profit.

In general, a lot of research and development will have to be done to make a significant contribution to capture production. The need of rebuilding wild stocks will not be evaded by aquaculture. Cod farming is expected to make a contribution to the supply at least in Norway but it will likely neither substitute capture production nor solely solve supply problems.

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