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# New Developments in Biotechnology and IPR in Aquaculture – Are They Sustainable?

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## 1. Introduction

The objective of this chapter is to give an overview and analysis of the current trends and developments in biotechnology in aquaculture research and management. The technological developments along with structural changes in the aquaculture sector may affect access and intellectual property rights (IPR) regimes. These issues will be discussed in a wide perspective involving both short and long-term biological effects, ethical and other social aspects (economic, legal and political issues), including their partly inherent contradictions needing compromising for sustainable development. The chapter will focus on current biological challenges within aquaculture as a growing food production sector, with less emphasis on external effects such as environmental effects. Cases from farmed salmon and cod in Norway in addition to shrimp and tilapia in Asia will be highlighted.

## 2. Concept of sustainable development in aquaculture

Since the publication of the World Conservation Strategy, the concept of 'sustainable development' has received increasing importance in most policy areas. A widely used definition of the concept is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). The Rio declaration of 1992 clarified that governments have a global responsibility for resolving conflicts over the environment in ways that protect the interest of humanity and nature. One good example of international obligations that has included the concept is the Convention of Biodiversity (CBD). With regard to aquaculture, recommendations for employment of sustainability can be found in the Holmenkollen guidelines for sustainable aquaculture (1999), in the Norwegian ministry of fisheries and costal affairs strategy for an environmental sustainable seafood industry (2009), and in the EU communication; A strategy for the sustainable development of European aquaculture (2002).

Critics of the concept of sustainable development have, however, argued that the concept is elusive, and highly varying views persist among both scientists and regulators with regard to what the concept constitutes and implications by implementation. The main contested values and practices of sustainable development are: what values are important within sustainable development and how to set priorities between them, and how to achieve maintenance and preservation of nature and biodiversity versus a just society and economic development (Kamara et al., 2006). For example, the rapid spread of aquaculture has raised concern about land-use change in coastal areas, impacts on wild fish by escapees, environmental pollution, and extensive use of marine resources for fish feed production. A conceptual framework for sustainable aquaculture has been presented from three perspectives: environmental, economic and sociological (Caffey et al., 1998). This implies that introduction of modern biotechnology must be explored both with regard to the adequacy of present approaches and with regard to the problem solving nature of the new technology. Moreover that there needs to be an awareness that application of modern biotechnology in aquaculture also influences socio-economic values as employment, income, and local economic activity as well as ethics, which are all important elements of sustainability as understood by most users. Hence, sustainable development requires a renewed focus on stakeholders and their needs, it demands clearer understanding of stakeholders perspectives and public concerns as well as attention to issues of institutional structure and representation in decision-making processes.

The next section deals with biological/ecological challenges in aquaculture while section four provides a picture of recent technological developments that may have a bearing on these challenges. In section five we present international and domestic regulations relevant to both modern biotechnology and the access issues, thus pertaining to the discussion of sustainability. We then briefly account the present structural developments and management trends within aquaculture. With this broad framework in mind, we turn to examine actor perceptions of how biotechnology and IPR may affect sustainability in aquaculture. This section builds on surveys and interviews with key actors. Then in section eight we highlight some of the major issues for understanding how IPR and biotechnology may affect sustainability in aquaculture. Finally we discuss implications and give some recommendations for how developments in biotechnology and IPR in aquaculture can contribute to sustainability.

## 3. Current management and biological challenges within aquaculture

Aquaculture industry is currently facing many challenges. These involve animal health and welfare, environmental effects and social effects including economics, global and fair utilization and sharing of resources, rural viability etc. Within the format of a book chapter, only a limited number of challenges can be handled properly. The focus of this section will therefore be limited to biological challenges with emphasis on animal health and welfare, and the management of fish breeding including biotechnological methods.

### 3.1 Search for improved animal health

The growth in aquaculture has been accompanied with an increase in diseases caused by pathogens that includes a wide range of bacterial, viral, parasitic and fungal infections. At present diseases in aquaculture are causing big economic problems and are affecting animal welfare significantly. The high density of fish together with the effective pathogen transportation in water creates favourable living conditions for these pathogens. Hence, diseases tend to multiply in farm environments, a situation that represent potential ecological threats both to the farmed fish in itself and to the farm environment including wild fish. In salmon aquaculture disease prevention with antibiotics and chemicals was for many years the solution preferred. However, the potential pollution associated with chemicals and the excessive use of antibiotics together with the emergence of multiple resistance to antibiotics created concerns and initiated a search for alternative ways, as selection for increased disease resistance, to deal with the problem.

Selection for increased disease resistance in fish has mainly been based on challenge tests carried out under controlled conditions. Challenge-tested fish cannot be used as parents for the next generation of elite salmon, meaning that selection cannot be applied directly on the breeding candidates. To circumvent this problem, geneticists have been searching for genes controlling the degree of resistance to different diseases. Markers for such genes may be ideal criteria for selection, because they can be applied directly without requiring challenge testing (see also section 4.2). Thus, the accuracy of selection can be increased while the need to sacrifice fish in challenge tests is reduced.

Selection for genetic disease resistance has been emphasized in Norwegian salmon breeding since 1995. In 2007, Moen et al. (2009) identified markers for a gene that explains most (80 %) of the genetic variation in resistance to infectious pancreatic necrosis (IPN) in both fry and post-smolts. Based on these findings, Aqua Gen has developed and applied a tool using these markers for selecting IPN-resistant fish directly. This tool can, with very high accuracy, determine whether individual fish have zero, one or two copies of the gene variant (allele) that give high resistance. This approach may also be useful for pancreas disease (PD), which is an important economic disease of farmed Atlantic salmon that cause significant losses through mortality and reduced production (SalmoBreed, 2011).

Currently, salmon lice (*Lepeophtheirus salmonis*) represent a major health and welfare problem in the salmon industry. Furthermore, it is also an ecological problem, since the lice multiply in fish farms, and then spread to the wild salmon population. Chemical treatment is commonly used to combat the lice, but use of biological measures such as cleaner fish has increased lately due to development of resistant lice to the chemicals. However, moderate genetic variation has been shown for resistance to the salmon louse, and thus it may be possible to reduce problems caused by lice through selective breeding programs (Kolstad et al., 2005). Breeding for disease and parasite resistance in Norwegian salmon and trout is considered to be important for the fish themselves, producers and consumers alike and would increase the sustainability of the industry, and the know-how could be transferred to other aquaculture species.

### 3.2 Genetic diversity and fish breeding strategies

Substantial long term selection responses of 10-15% higher growth rate per generation have been documented for several species of farmed fish, such as Atlantic salmon in Norway since the 1970'ies and Nile tilapia in Asia since the 1990'ies. Highly favorable benefit cost ratios ranging from 8 to 60 is reported for fish breeding. Due to the high fertility of fish and convenience of handling and distributing seeds, such high benefit cost ratio can be obtained for fish breeding programs. For this it is, however, important to note that an efficient dissemination structure and organization reaching a high number of farmers is crucial. In Norway, seed from the improved farmed salmon was sold to the farmers as eyed eggs and smolts. As the genetic gain became more apparent, the demand for genetically improved salmon increased rapidly during the first decade. Until the market demand and dissemination was appropriately developed, public funding allowed for establishment of the salmon breeding program. During the early 1980'ies, the Norwegian Fish Farmers Association got involved in the program, and in 1992, the breeding program was turned into a private company, Aqua Gen, a sustainable business with long term profitability. The GIFT (Genetic Improvement of Farmed Tilapia) program is another example of a successful breeding program resulting from public funded research and technology development. The GIFT seeds have been disseminated to several countries in Asia and Latin America to support intensive large scale farms and small subsistence farms.

Genetic variation is essential for selection response, and a sufficiently large and genetically diverse breeding population is, therefore, fundamental when establishing and running an animal breeding program. A breeding design with appropriate family structure is critical to maintain a large effective population size and obtain a long-term selection response with low rates of inbreeding in fish breeding. For mass selection, Bentsen & Olesen (2002) concluded from a simulation study that a minimum of 50 families (pairs of parents) are required to prevent inbreeding and obtain a long-term response in a mass selection program for aquaculture. Gjerde et al. (1996) presented optimum designs for fish breeding programs with constrained inbreeding and mass selection. Various breeding designs for between-family, within-family, and combined selection (between- and within-family) are presented and evaluated by Bentsen & Gjerde (1994). Combined family based selection designs may improve the accuracy of selection substantially, particularly for traits with low heritability. Due to the higher probability of selecting large numbers of sibs from a few families the number of broodstock selected per family needs to be restricted to avoid a high rate of inbreeding and reduced genetic variation.

Less than 10% of the fish stocked for aquaculture in 2005 originated from family based selection programs (Gjedrem et al., 2011). This situation has not improved much recently, and for many aquaculture species with huge production quantities, such as carps, only a few efficient selection programs are active. Furthermore, the effective population sizes are often limited and in some cases too low, because the high reproductive capacity allows the use of a low number of broodstock. Such populations may still gain sufficient short-term advantage above non-improved populations and capture much of the market share. In turn, this discourages further genetic introductions into the breeding nucleus. Long-term inbreeding and loss of genetic variability because of genetic drift may then affect performance and further the long-term genetic progress. In such populations, strategies for continuous (re)introduction of genetic variability from outside the breeding nucleus without adverse performance consequences are, therefore, required. Furthermore, initiation of additional breeding programs is expected for different environments for the most important farmed species and this may improve the situation.

### 3.3 Prospects for genetic improvement of fish welfare

During the initial stages, breeding programmes for farmed fish usually focus on improving productivity traits such as growth. During later stages, disease resistance, survival, and product quality traits are often emphasized during selection to develop a more robust fish. Domesticated fish fit better for a life in captivity and farm environment, and are therefore less stressed and will be more robust and perform better with respect to growth and survival. Hence, maintaining good fish welfare by reducing stress load and making sure the fish is thriving will be a key to promote a more robust fish and profitable farming.

Huntingford et al. (2006) list several factors in aquaculture that represent fish welfare challenges including aggressive interactions, handling and removal from water, diseases and permanent adverse physical states and possibly increased levels of aggressiveness due to selection for fast growth. However, it has been shown in both salmon and cod that after a few generations of selection for growth and domestication in hatcheries and farms, we obtain calmer, less aggressive carnivorous fish. In a review of the effects of domestication on aggressive and schooling behaviour in fish, Ruzzante (1994) conclude that domestication may strongly affect behavioural traits, but it is the intensity of the behaviour rather than the behavioural pattern itself that is affected. Olesen et al. (2011) emphasised possible correlated effects on stress coping for fast growing fish.

Selection for high production efficiency in terrestrial animals is known to give undesirable effects in traits like health and reproduction (Rauw et al., 1998). However, in the Nordic countries broader breeding goals including functional and welfare traits have been selected for. Olesen et al. (2000) discussed definition of breeding goals for sustainable farm animal production, and suggest a procedure including non-market values for appropriate weighing of traits providing public goods (e.g. welfare traits). Since 1995, farmed salmon in Norway have been selected for resistance to diseases. Such selection will obviously reduce stress and suffering connected to diseases. Particularly for farmed fish, there is a lack of information on genetic variances and covariances of many welfare related traits such as behaviour (e.g. aggression) and stress coping. Consequently, we do not know possible unfavourably correlated responses in some fish welfare indicators, e.g. poorer ability to cope with stress, resulting from the current selection for productivity traits. Hence, more knowledge and research is needed on fish welfare traits and their genetic parameters. Regarding survival and maturation, behaviour, dominance, aggressiveness and activity level, it is reported genetic differences between wild and farmed salmon (Fleming & Gross, 1992; McGinnity et al., 1997; Metcalfe et al., 2003; Petersson & Järvi, 2006). Hatchery reared salmonids showed a weaker antipredator response (Johnsson et al., 1996) and less physiological stress due to higher stocking densities (Mazur & Iwama, 1993) when compared to the wild. As farmed fish adapt to the farm environment, such domesticated fish will suffer less in the farm environment. Relevant fish welfare indicators or traits that currently can be taken into account in selective breeding are growth, survival (or mortality), social interactions/behaviour (e.g. cannibalism for carnivorous species) and frequency of injuries (e.g. fin injuries) (Turnbull et al., 1998).

### 3.4 Animal welfare and animal ethics

Promoting good husbandry practices and ensuring the welfare of farmed fish are well-established parts of the European Union policy for sustainable aquaculture development. However, there are often conflicts and trade-offs between short term profit of the industry and demand for cheap animal products on one hand and animal welfare on the other, that the animals do not gain from. Animal welfare has mostly been discussed in relation to research animals, land based animals for food production, and pets. Some of these issues will be highlighted before we move into implications of fish farming on animal welfare.

An important question with regard to animal husbandry is if it is morally legitimate to use animals merely as a resource or means to meet our needs, or if there are moral considerations that place restrictions on such an approach. Many difficult questions have arisen with regard to animals' intrinsic value. Assuming that animals do have intrinsic value, all encroachments on their lives (by humans) become moral issues and demand carefully considered answers and actions. The Norwegian Animal Welfare Act of 2010, states that animals have an intrinsic value. This term implies that animal welfare must be prioritised irrespective of the value the animal may have for people, which also contributes to clarifying the animal's status.

The word 'welfare' is derived from *well* + *fare*, i.e., how well (or dignified) an animal 'fares' (travels) through life. How well is an animal able to regulate its biological functions in relation to its environment? A function based definition of animal welfare is given (Broom, 1986): 'The welfare of an animal is its state as regards its attempts to cope with its environment'. Other definitions focus on an animal's subjective experience or awareness of its condition (feeling based) and/or on whether it can live a natural life (nature based). Hence, the term 'animal welfare' applies to both the mental/emotional and physical health of the individual animal or the animal's condition while trying to cope with its environment. The term also includes behaviour, as well as physiological and immunological factors. In this context, health is defined more broadly than merely the absence of disease. An important basis for ensuring animal health is the animals' well-being. It also includes positive welfare, with the implication that denying animals positive experiences and stimuli is also an ethical problem with regard to animal protection. 'Animal protection' is here seen as the protection of the emotional and the physical health of individual animals.

Most current animal ethicists use animal ability of sentience for ascribing direct moral considerations. Lund et al. (2007) claimed that fish welfare should be given serious moral considerations depending on their possession of the morally relevant similarities of sentience. The same authors reason further that fish are likely to be sentient and therefore deserve serious consideration. They also concluded from a simple risk analysis that the probability that the fish can feel pain is not negligible, and that if they really experience pain the consequence is great due to the possibly high number of suffering animals. Hence, farmed fish should be given the benefit of doubt. Even from a more egoistic standpoint, we can argue for fair treatment of animals. If we inflict suffering upon animals, we violate human dignity and may contribute to the development of a crueller society, as also indicated by Mahatma Gandhi ('The greatness of a nation and its moral progress can be judged by the way its animals are treated.').

## 4. Biotechnology in aquaculture and its role in innovation

Modern biotechnology does involve new tools to meet several of the challenges that aquaculture is at present striving with. In this chapter we will therefore limit our presentation to breeding and vaccine development and then to the promising possibilities by chromosome manipulation, DNA marker selection and genetic engineering.

### 4.1 Reproduction technology involving chromosome manipulation

In most aquaculture species, external fertilization is natural, and opens many powerful methods of genetic engineering, including manipulation of chromosome number such as haploids and polyploids with three (tetraploids) and four sets of chromosomes (tetraploids). Furthermore, animals with chromosomes from only the dam (gynogenesis) or from only the sire (androgenesis) can be produced. A more comprehensive overview of the techniques involved and applications is given by Refstie & Gjedrem (2005).

Production of sterile fish may solve the problem of escaped fish interacting with wild fish and the need for protecting improved genetic material against ‘piracy copying’. Early sexual maturation cause problems in commercial farming due to poorer filet quality, higher mortality and reduced growth. Sterile triploid fish will not produce gonads and can continue growing and being slaughtered at any time. For many species, one of the sexes gets earlier sexual mature and hence lower growth and body weights. Chromosome manipulations can be used to produce either all male (as in e.g. tilapia and salmon) or all female fish (as in e.g. halibut, hake and angler fish) depending on the sex preferred. Triploid trout and all male tilapia are the most common applications of chromosome manipulations in aquaculture.

Questions of cost/benefit analysis that need to be addressed before using reproduction technology are: is one gender more highly priced by the market; is one gender of higher production value to producer; is gender determination known for the species or is it mainly environmentally induced, will ‘clean green’ market perception/sales pitch be jeopardized by the use of this technology (Robinson, 2002).

### 4.2 Application of molecular genetics in aquaculture breeding

The two areas of modern biotechnology that has been expected to have most significant impact on genetic improvement of aquaculture species are DNA markers and transgenics (Hayes & Andersen, 2005). A DNA marker is an identifiable physical location on a chromosome whose inheritance can be monitored (Hyperdictionary, 2003). A comprehensive overview of DNA markers and linkage mapping together with a discussion of potential applications of DNA markers in aquaculture breeding programmes is given by Hayes & Andersen (2005). Furthermore, whole genome sequencing and application of genomics in aquaculture breeding programs is discussed by Quinn et al. (2011, see chapter in this book). As mentioned, DNA markers have already been applied in aquaculture breeding for direct and highly accurate selection of IPN-resistant fish (Aqua Gen, 2010). So called marker assisted selection (MAS) can double genetic gain for traits that can not be measured on selection candidates (e.g. disease resistance), because it utilizes the between family variance, and may also contribute to reduce inbreeding. For MAS, quantitative trait loci (QTL) must be mapped and their effect determined. This is not the case for genomic selection (GS), where the effects of a large number of loci are first estimated using a test group. Selection can then be carried out on genome wide breeding values of the breeding candidates predicted as the sum of the marker effects estimated, assuming an additive genetic model (Meuwissen et al., 2001). However, the high genotyping costs for GS has so far limited its application in aquaculture breeding. Therefore, a scheme with pre-election of parents for growth combined with selective genotyping of large and pooled family groups has been suggested to obtain high accuracies while reducing number of genotypes and costs many fold (Sonesson et al., 2010).

Furthermore, application of new tools of molecular genetics for gaining understanding about genetic regulation of complex traits such as disease resistance may be important (see section 3.1).

### 4.3 Genetically modified organisms

The possibilities within modern biotechnology related to the ability to identify genes endowing specific phenotypes together with projects intended to map genomes have opened the possibility for the development of genetically modified organisms (GMOs). Of special relevance for aquaculture are research and development of transgenic fish, GM vaccines (here also included DNA vaccines) as well as present and future GM plants to be used in feed. Genetic engineering can also be a useful tool for increased use of IPR, as it may make it easier to fulfil patent criteria such as the inventive step and the demand for reproducibility.

#### 4.3.1 Introduction of transgenic fish

Most focus on trangenic fish is on the possibilities for enhancement of the quality of cultured stocks by improving growth rate and increasing resistance to disease and stress (Melamed et al., 2002). Improved growth rate has been possible by the introduction of growth hormone (GH) genes, in species such as Atlantic salmon, coho salmon, Nile tilapia and hybrid tilapia. The most known example of transgenic salmon is the *AquAdvantage*, developed by Aqua Bounty, which contains a gene construct composed of the regulatory elements of an ocean pout antifreeze protein gene controlling a chinook salmon GH gene. The antifreeze promotor enables stimulation of the growth hormone gene also during cold periods with the result that the transgenic salmon grows much faster than its non-GM counterpart. The company is seeking approval for commercial use of this transgenic fish, and the application has been under evaluation in more than ten years by the US Food and Drug Administration (Niiler, 2000). Other highly relevant approaches are development of disease and parasite resistant fish. At present there is a lack of understanding of genes responsible for disease resistance in fish and different strategies are discussed. These strategies include antisense technology for production of complementary RNA for foreign RNA, expression of antimicrobial substances and peptides (as lysozyme) and efforts to increase production of the fish cytokines and other genes involved in immune defence. Moreover transgenic approaches that combine interesting characteristics, as enhanced growth and disease resistance, together with approaches for development of sterile fish or fish where reproductive activity can be down-regulated is also highly relevant since this will minimise the risk of transgenic fish breeding with wild populations after accidental release or escape.

The potential of transgenic fish to escape and enter the natural environment is an important concern for regulators (Le Curie-Belfond et al., 2009). Unless transgenic fish is used in contained facilities, transgenic fish will certainly escape into the environment. The environmental impact is difficult to predict and will depend on the number of escaped fish, their phenotypic characteristics (related to ability for reproduction and survival over time), and the aquatic biodiversity present in the receiving ecosystem (Kapuscinski & Brister, 2001).

Another potential problem related to transgenic fish that is disease or parasite resistant may be similar to what has been experienced with insect resistant crops (Le Curie-Belford et al., 2009). It has for example been reported that insects have developed resistance to insect resistant crops. Hence, the benefit achieved may over time develop into a long-term problem. If the same unexpected events develops with disease or parasite resistant fish the consequence will be a need for more or other antibiotics and chemicals to cope with resistant pathogens and parasites or new emerging pathogens.

Development of transgenic fish does also raise ethical concern. One implication by the genetic modification process itself is that it may affect fish welfare, behaviour and reproduction (see also Le Curie-Belford et al., 2009). It has been reported pleiotropic effects as changes in coloration, cranial, opercula and lower jaw deformation in transgenic coho salmon (Devlin et al., 1995). Concerns have also been raised that genetic modification strategies may affect the animal's integrity (Verhoog, 2001). This is controversial, and for example Sandøe & Holtug (1998) argue that only welfare of animals and humans are relevant ethical considerations, and that these considerations imply to:

1. Clarify realistic alternatives for improving animals welfare through breeding or biotechnology
2. Consider positive and negative effects on animal welfare
3. Find what benefits are at stake for humans
4. If animals welfare is reduced, consider if the costs of animals will weigh up for humans benefits
5. Weigh conflicting concerns, including risk of possible long term side effects.

When weighing conflicting ethical concerns we often have to compromise between efficiency and animal welfare, where different ethical theories of animal ethics may affect acceptance of biotechnology on animals (Sandøe & Christensen, 2008):

- Contractarianism: implies no problem with instrumental use of animals as a biotechnological resource or as a tool for biotechnology.
- Utilitarianism: can accept the use of biotechnology to improve human and animal welfare if the benefits are bigger than the costs in terms of harmful effects.
- The animal rights view: makes the use of biotechnology in animals more problematic. One can for example not sacrifice a live animal and make it suffer from e.g. health problems in order to improve animal health of future generations of an animal population. If there is a risk that e.g. transgenic fish have unintended health problems, this will be particularly troublesome. Use of both animal breeding and biotechnological methods on animals can be considered as instrumental use of animals and does therefore interfere with this view although it may not imply important harm or suffering for the animal.
- Respect for nature often implies moral problems with both animal and plant breeding and biotechnology. Those who sympathise with this view will often be critical to tamper with the nature although it may not cause animal or human harm or suffering. Hence, they will only support a very cautious and restrictive policy to animal breeding and biotechnology. For farmed fish with close wild relatives in nature this will likely be even more troublesome than for other farm animals. The risk of escaped farmed transgenic fish mating with wild fish is for example particularly problematic in the view of natural populations almost considered as sacred. Traditionally bred farmed salmon with the same alleles as wild salmon, but with other gene frequencies and other combinations can also be troublesome for the same people. When it comes to salmon, the fact that it is often considered as an iconic species may also be a relevant issue.

In the Norwegian Animal Welfare Act (2010) §25, the following is stated about animal breeding: 'Reproduction, including through methods of gene technology, shall not be carried out in such a way that it:

- changes genes in such a way that they influence the animals' physical or mental functions in a negative way, or passes on such genes,
- reduces the animals' ability to practise natural behaviour, or
- stimulates general ethical reactions.

This may reflect a hybrid view including utilitarian (first two points) and animal rights based (third point) views. The first point (animals' normal functions) may also have an element of respect for nature. One may therefore argue that such a hybrid may be the base for the public ethical view on using transgenic animals in Norway.

#### 4.3.2 IPR and the introduction of GM and DNA vaccines

Modern biotechnology provides tools both for rapid detection and identification of disease and holds promises for new and improved vaccines. Generally spoken, there are two strategies for GM vaccine development: The first is represented by gene-deleted bacteria/ viruses to be used for homologous vaccination, i.e. to achieve protective immunity against the GM vaccine itself. The other strategy involves development of recombinant vaccines by genetic engineering where a gene that is immunologically targeted to a) be expressed after insertion in bacteria or yeast and the proteins produced are then further incorporated into a vaccine preparation, b) be inserted in a virus or bacteria by recombination and the recombinant virus or bacteria is then used as a vaccine, and c) DNA vaccine.

In aquaculture the most effective vaccines at present are multivalent (contains several genes of interest) and target salmon, there is also ongoing research to develop vaccines for other species (as seabass, tilapia, grouper etc.). Present approaches are, however, limited to some bacterial and viral diseases while there are no vaccines against parasites of fish. Especially intracellular pathogens, such as virus and some bacteria, have been found to be difficult to eradicate with traditional vaccines. Hence, DNA vaccines may offer a technological solution to these problems. An example of a DNA vaccine is the plasmid encoding infectious haematopoietic necrosis virus (IHNV) glycoprotein under control of a cytomegalovirus promoter (pCMV), which has been injected in Atlantic salmon with the purpose of achieving resistance to IHNV (Traxler et al., 1999). Following early trials on DNA vaccination in mammalian species, several experiments have been conducted in fish with promising results, such as complete protection against viral diseases (Romøren, 2003 and references therein). A combination DNA vaccine, consisting of multiple plasmids encoding several different antigens of a pathogen, holds prospect for inducing a broad spectrum of antibody responses, and hence be effective for vaccination against viruses that undergo antigenic variation (e.g infectious pancreas necrosis virus (IPNV) and infectious salmon anaemia virus (ISAV)) (Kibenge et al., 2001).

The development of both GM and DNA vaccines against infectious fish diseases has several attractive benefits: low cost, ease of production and improved quality control, heat stability, identical production processes for different vaccines, and the possibility of producing multivalent vaccines (Hew & Fletcher 2002; Kwang 2000). On the other hand, there is at present a limited scientific understanding of the fate of such vaccines after injection into the animal. There is a need for research with focus on the stability of the vectors and of the DNA construct, and if there are any unintended immunological impacts, the biological effect of the vaccine after injection (e.g. persistence, distribution, expression and integration) (Gillund et al., 2008a, 2008b). For GM vaccines it is important to investigate potential recombination with relatives and spread in the environment by vectors (Myhr & Traavik, 2011).

An example of the socioeconomic dilemmas relating to IPR, is the case of Intervet's patent on the Pancreas Disease (PD) virus and whether it is a potential barrier to further development of a PD vaccine or not. As the patent has been given on the virus itself, this gives Intervet full monopoly on developing vaccines against Pancreas Disease (PD). Pharmaq wanted a license to produce a PD vaccine and asked the competition authorities for a compulsory licence without success. They argued that the current Intervet vaccine is inefficient and their production is insufficient, and that their own vaccine is superior in terms of time, costs and animal welfare as it can be given as a component of one injection of multi-vaccination (Haavind Vislie, 2008). The Ministry of Fisheries and Coastal Affairs (FKD) was not directly involved although the competition authorities asked for their opinion. In a trial case, Pharmaq have emphasised that they apply a variant of the PD virus that is different from PD virus patented by Intervet. The case is still open as this book is published.

## 5. International obligations and examples of domestic regulations: How they address sustainable development in aquaculture

As we have seen in section two to four, the biotechnological developments open for benefits, but do also represent new challenges with regard to how they affect economic, social and environmental conditions. This section describes how these activities are sought regulated at the international and domestic arenas in order to enhance sustainability in the aquaculture sector. The section provides an overview of two different sets of legal provisions; the first bulk is rather voluminous and is aimed at access and benefit sharing legislation and hence, only indirectly dealing with the issue of sustainable development. The second is much less developed at the international and national arenas but these legal acts and instruments are more directly dealing with sustainable development in aquaculture. Both aspects are relevant to the Convention on Biological Diversity (CBD). At its second meeting (November 1995, Jakarta, Indonesia), the Conference of the Parties (COP) to the CBD agreed on a programme of action called the "Jakarta Mandate on Marine and Coastal Biological Diversity," which led to the creation of a work programme in this area.

The Convention on Biological Diversity has three interrelated objectives: Conservation and sustainable use of biodiversity, and access and equitable sharing of benefits from use of genetic resources. The scope of the CBD covers conservation and sustainable use of wild species and improved breeding stocks, as well as equitable sharing of benefits derived from the use of the world's genetic resources. This issue has been subject to controversial negotiations over the years since the establishment of the CBD. Negotiations recently resulted in a Protocol on Access and Benefit Sharing at the 10$^{th}$ Conference of the Parties to the CBD in Nagoya, October 2010.

The World Trade Organization (WTO) establishes global standards for harmonisation of intellectual property rights and the World Intellectual Property Organization has as its mandate to strive towards cooperation and harmonisation of IPR in all member countries. Harmonized IPR regulations target all technological fields similarly, including biotechnology and when biological material forms part of the invention. The tension between the overlapping objectives of the various international treaties is a controversial north-south issue.

Two changes in patent law have made the patent system controversial: First that patents are granted on various forms of biological material; and second that patents are granted to essentially basic research, increasing the commercial aspects of research. These tendencies raise questions about whether patents contribute to innovation or not. Also the link between exclusive rights and access rules is problematic, as very limited amount of benefits arising from utilization of genetic resources have been shared with providers. The CBD seeks to balance expanding patent regimes by establishing a compromise between access to technology and access to the input factors in biotechnology – genetic resources (Koester, 1997; Rosendal, 2000). This interaction between different international objectives has caused North-South conflicts over access to seeds and medicinal plants versus patented technology in the agriculture and medicinal sectors. This is different for aquaculture and animal husbandry where breeding material has usually not moved from south to north.

Access to genetic resources, conservation, equitable sharing of benefits, and IPR systems to boost innovation – are all internationally agreed objectives – but they are not necessarily mutually compatible (Rosendal, 2006). Conservation is basically a prerequisite for all the other objectives, as acknowledged in the three objectives of the CBD. The essence of the CBD is to tie the balance between ABS and IPR to that of conservation: Without access to the genetic resources, there can be little innovation. The CBD attempts to establish a system for innovation based on biodiversity to contribute in a fair manner to the conservation of the diversity. IPR legislation seeks its justification in increasing the incentive for innovation. There are, however, indications that broad patent claims have the potential also to hamper innovation by stifling access to technology and increase the transaction costs for other actors. Without innovation, there may be fewer benefits to share. Without benefit sharing from utilisation of genetic resources, there may be less will and ability to conserve biodiversity in developing countries – although this particular dimension has less immediate relevance in aquaculture compared to the agricultural and pharmaceutical sectors (FAO, 2009).

Turning to domestic norms and regulations and applying Norway as an example, the overall goals for aquaculture are linked to safeguard coastal settlements and increase value, sustainable management and innovation (White Paper, 2005:9, 136). Norway acknowledges responsibility for about one third of the world's remaining populations of wild salmon, as well as environmental responsibilities through Norwegian owned salmon farms including production in other countries (White Paper, 2009:142). This raises interesting questions about the relationship between Norwegian utilization of this resource and Norway's responsibility for managing the wild material according to the CBD.

At the domestic level, Norway has recently developed two relevant legal acts: The Nature Diversity Act of 2009 and the Act on Management of Wild Marine Resources of 6$^{th}$ June 2008. The Wild Marine Resources Act grants discretion for the government to establish a procedure of governmental permission before bioprospecting of wild marine genetic resources and is hence of less immediate relevance for export from breeding programmes. The Nature Diversity Act establishes genetic material as a commons resource that should remain a common property resource in Norway, and it also gives the Ministry the discretion to require permits for accessing genetic resources. Also the Marine Resources Act states that marine resources are a common resource. Both Acts require the respective ministries to supplement the legislation with detailed administrative regulations for access to genetic resources, but several challenges remain in developing these regulations. One is the relationship between access to the resources and the right to use it for a patented invention. Export of fingerlings and breeding material will invariably include the genetic material – and may hence require special protection in order to secure the interests of the exporter to maintain these resources as a commons.

Let us now turn to instruments that are more directly trying to tackle environmental concerns in aquaculture. Most central of these is the emerging Aquaculture Stewardship Council (ASC), which is expected to be in operation by 2011 as the world's leading certification and labelling programme for responsibly farmed seafood. The ASC is the outcome of the Aquaculture Dialogues and it will be responsible for working with independent, third party entities to certify farms that are in compliance with the standards for responsible aquaculture, which is created by the Dialogues. These standards are designed to minimize the key negative environmental and social impacts related to 12 aquaculture species. Similar to those of the Forest Stewardship and Marine Stewardship Councils, these standards prescribe quantitative performance levels that farmers must reach to become certified. More than 2,000 aquaculture producers, conservationists, scientists and others are involved in the process, which is coordinated by World Wildlife Fund (WWF). Along with the Dutch Sustainable Trade Initiative (IDH), the WWF also help fund the development of the ASC, which will be a non-profit organization.

## 6. Structural developments and management trends in aquaculture

The new promises and threats of the technological developments provide a backdrop also for this section, which is aimed at combining technology and structural trends. The general structural trends in aquaculture are similar to those in agriculture and animal husbandry worldwide, that is to say moving away from public funding and small scale enterprises towards merging, privatization and internationalization. In this section we briefly account for these trends and then in section eight, we point to some of the implications this may have for management and sustainable development in aquaculture.

In Norway, salmon and trout breeding programs were started with public financing in 1971 by a non-profit research institute (Gjøen & Bentsen, 1997). The base populations of these programs were collected from Norwegian rivers (Atlantic salmon) and from Scandinavian farmed populations (rainbow trout) and these breeding populations were transferred in 1985 to a cooperative ownership by salmon farmers' organizations. However, as a result of an economic crisis in the late 1980s, this activity was transferred to a shareholder company in 1992 (at present Aqua Gen AS). At that time it was decided that the value of the breeding material should be secured in a way that took care of the public interest; hence the structure of ownership was divided between private and public shareholders, but that structure was only bound for a five years period. With the next government the largest public shareholder was turned into a private venture company, who in 2007 decided to sell its shares in Aqua Gen AS. The German EW Group, which is also the holding company of the world's leading poultry genetic companies (Aviagen), concluded an agreement to take majority ownership of the shares in Aqua Gen AS. Thus, the Ministry of Fisheries and Coastal Affairs (FKD) gradually lost control over the material from the originally public supported breeding programme for salmon.

Currently, the Norwegian legal system is unclear on regulating genetic material originating in the wild or coming from public breeding programmes and hence a comprehensive management system for aquatic genetic resources is not in place. The sale of Aqua Gen AS to German EW Group is illustrative of the dilemma. This breeding material can now in theory be patented and removed from the public domain. The development has moved from a situation of public control and ownership, via a cooperative situation, to the current situation of increasingly dominating market actors. This raises question about eventual effects of recent Norwegian access regulations in the Nature Diversity Act and the Marine Wild Species Act. The situation has raised questions about the need to regulate access to wild or breeding material in other species, as cod and halibut, because a similar level of international exchange has not taken place for these other species of fish.

Since the early 1990s, public support for Norwegian farm animal breeding has decreased, reflecting a political will to privatize breeding. A counter trend is the initiative from the Ministry of Fisheries and Coastal Affairs to fund the establishment of a breeding program for cod at the research institute, Nofima in Tromsø. In line with the policy goal of safeguarding rural settlements, this may reflect an intact willingness to finance development of breeding programmes in Norway, at least in the districts of Northern Norway. The current official goal is to retain the cod breeding material and associated competence and knowledge bases that are being built up as a Norwegian public good asset. The end goal may be that cod, like salmon, is intended to become profitable and commercialised at some point down the line, but the legal process of how to deal with this has only just started (interview NN1).

## 7. Actor interests responding to structural and technological changes

In this section we turn to the description of how affected actors perceive the legal, structural and technological developments in the aquaculture sector. The aim is to study their views on whether and how these parallel trends are likely to affect sustainable development in aquaculture.

### 7.1 Public opinion and attitudes to new biotechnologies

In Europe, surveys have been carried out from 1996 to 2007, to identify Europeans opinion and attitudes to modern biotechnology. Although difficult to draw any conclusion it seems that modern biotechnology used in production for medicines and pharmaceutical products receives highest support while modern biotechnology used in agriculture receives less support (although concern about GM foods have had a small decline since 2001). For example in one recent Eurobarometer poll (GMO compass, 2009), European consumers were asked to identify the environmental themes about which they were most concerned, and on an average, 20% of respondents cited the topic of 'GMOs in farming'. Although these surveys have been on GM crops and medicines, the aspects related to benefits and environmental issues may have similar support and doubt versus the different possibilities for introduction of modern biotechnology in aquaculture (see also 7.1.1 for results from a survey among Norwegian students).

There are several challenges involved in measuring actor perceptions of GMO. A study of the GM debate in the UK, Australia and New Zealand found that access to decision-making and the inability to weigh explicit social value judgements with the broad science consensus were the major obstacles to successful deliberative public debate (Walls et al., 2005). For instance, in the New Zealand experience, non-scientific arguments were implicitly marginalised because the templates (questionnaire) employed for the interest groups made it difficult to use holistic arguments. A 'holistic argument' in this case might imply a consideration of the growing dominance of multinational corporations in the life sciences. These enterprises increasingly decide on options for the development of new medicines and food, they are part and parcel of the GM revolution – but somehow their role seemed to be 'beside the point' in the questionnaire developed to study the public debate (Walls et al., 2005). Most studies on GM plants and products are based on information provided by research laboratories and/or released by industry (Gaskell et al., 2003). It is also important to note that this documentation, along with the GMO applications, is provided by multinational corporations that enjoy little public trust (Gaskell & Bauer, 2001).

### 7.1.1 Students attitudes to the use of GMO in aquaculture

Knowledge and attitudes regarding the use of GMOs in aquaculture was studied among students at the Norwegian University of Life Sciences (UMB) that can be considered as future stakeholders in food production and management of biological resources (Unpublished data). The survey result showed that most students were well informed about genetic engineering and/or GMOs. Many students were very concerned about environmental impacts from the use of GMOs. For example it was found that most of the respondents disagreed on the statement on whether the use of GMOs results in no negative environmental effects, this was also confirmed by the question on whether the students would buy transgenic salmon if it was more environmentally friendly (showed by an 40 % increase in willingness to buy transgenic salmon if it was more environmentally friendly). However, many students were not willing to buy transgenic salmon if it was more nutritious or more disease resistant. Only 47% of the respondents would buy transgenic salmon if a relevant authority (e.g. Norwegian Food Safety Authority) has approved it as safe.

Many students were totally agreeing that there is a need to reduce the risk by initiating more research on GMOs, that new knowledge about risks must be taken into account and that we need to seek expert advice to get more understanding about the potential risks to health and the environment. The students were also strongly agreeing on the need to reduce the risk of genetic engineering applications by increasing transparency to the public about research and information about the technology. Moreover, the need for improving communication between scientists and the public was recognized.

Spirituality or religion had little or no influence when it came to ethical issues by GMOs in this survey. Students supported use of GMOs for saving human lives (e.g. by producing medicines and vaccines) followed by production of animal feed (e.g. from plants, algae and microorganisms). Surprisingly, it was not found that production of cheaper food could encourage the students to support the use of GMOs. In general, students requested labelling of GM food as well as of salmon fed with GM plant feed.

### 7.2 Public attitudes to animal welfare and willingness to support and pay for e.g. improved health and welfare of farmed fish

In a recent study by Olesen et al. (2010) it was found that a relatively large percentage of Norwegian consumers agreed (at least partially) that Norwegian animal welfare standards were sufficiently strict (78,1%), and that fish welfare was sufficiently protected in Norwegian fish farming (67.9%). In order to estimate a lower bound for the consumers' willingness to pay for improved welfare for farmed salmon, a real choice experiment with eco-labelled salmon was carried out in Norway (Olesen et al., 2010). It was found that the average respondent preferred eco-labelled salmon to conventional salmon when the colour was the same, and was willing to pay additional 2 euro per kg fillet for eco-labelled salmon. The price premium depends on the conventional and organic salmon being the same colour, and an inferior appearance due to lack of pigmentation significantly reduces consumer interest in organic salmon. This is also consistent with the results in other studies investigating consumer preferences toward organic products with inferior appearance (Thompson & Kidwell, 1998; Yue et al., 2009).

### 7.3 Actor perceptions of needs and interests in access to aquatic genetic material

Studies of the fish breeding sector for several species and in several countries indicate that they are all prone to rapid structural changes in response to calls for profitability and commercialization (Olesen et al., 2007; Rosendal et al forthcoming). This correspond with a recent survey among fish farmers in Norway where it was found that the most important source of risk for the industry was future salmon prices, institutional risks and diseases (Bergfjord, 2009). In the same study the respondents (farmers) was also asked to identify the most important risk management strategies to the risk issues identified, which was to keep cost low and ensure profitability.

The public breeding programme on cod is currently seen as a public good for Norwegian breeders (interview NN2). The authorities are concerned that the public and private cod breeding programmes can compete on a level playing field, so that the one with public funding is not given unfair competitiveness. At this early stage, it is acknowledged that it is very hard to fund a breeding program, as the economic returns from increased growth may still be a long way off. For salmon, the real growth and economic returns from the breeding program was not apparent until about the fourth generation – and cod is still only in the second or third. There are two major reasons why public funding may be the preferred solution, at least in the early phases: First, during the early phases of breeding, basic mass selection using individual phenotypic information can provide a similar and much cheaper response in growth. This is why more advanced breeding programmes are often less profitable, particularly on a short term, as they are equally costly to start and run the first generations. However, phenotype or mass selection is usually much more limited with respect to selection towards a broader breeding goal with several traits, such as disease resistance. Also, it may be more vulnerable to less control of and rapid increase of inbreeding with resulting genetic erosion. Hence, in the long run, the more advanced family based breeding programmes will become more economically and biologically viable – or sustainable (interview, NN3).

Second, compared to a private breeding programme, aiming at short term profit, a public or cooperative programme usually have a broader range of breeding goals including animal welfare and environmental concerns. Hence, it is expected to obtain apparent gains in growth rate and economic returns later than a private programme – but to give more long term viable fish material and become more sustainable. This gives a competitive edge to the private cod programme in the short run and a competitive edge to the public one in the long run (interview NN1). In combination, they may be in line with the objectives stated in the White Paper for rural/coastal settlements, increased value, sustainable management and innovation (2005). Similar trends have been found for shrimp in India and tilapia in Asia (Ramanna Pathak, forthcoming, Ponzoni et al., 2010).

Considering the problems following Norwegian aquaculture investments and operations in Chile (where the entire salmon farming sector has recently been suffering from widespread outbreaks of infectious salmon anaemia), the enterprises expect to see stricter regulations regarding biological and environmental risks (Marine Harvest, 2011). New regulations will, however, require investment in new technology.

### 7.4 Researchers opinions and attitudes to new biotechnologies

Very few studies have been carried out with the intention to investigate researchers opinions and attitudes to new biotechnologies. In one study carried out by Kvakkestad et al. (2007) it was found that that different scientists, depending on scientific discipline (ecology, molecular biology, plant breeding), source of funding (public or industry) or whether they worked within industry, government or academia, interpreted data differently in situations characterised with uncertainty, and thus expressed a diversity of opinions about the risks arising from GM crops. In a recent study by Gillund and Myhr (2010) perspectives on alternative feed resources for salmon were identified among stakeholders in Norwegian aquaculture. In this study the sustainability of plant production in industrial agriculture, and particularly the cultivation of GM plants, was contested among the participants. The participants defined a broad range of appraisal criteria concerning health and welfare issues, economical issues, environmental issues, and knowledge and social issues, which illustrates that finding sustainable alternative feed resources is difficult.

## 8. Discussion

In spite of the tremendous benefit cost ratios and value creation for the society in terms of more efficient fish production and lower fish prices, only a small percentage (ca 10%) of the current world aquaculture production is based on genetically improved material from modern breeding programs (Gjedrem et al., 2011). The reasons that aquaculture is lagging tremendously behind the agriculture sector in this respect may be the lack of tradition and training of applying systematic selective breeding, little interaction with agriculture or aquaculture research groups with the knowledge and technology, low prices of roe and fry and resulting low profit margins of genetic improvement for breeders and hatcheries. The latter has made genetic improvement an insecure investment objective, perhaps also due to the ease of illegally reproducing highly fertile fish and marketing 'pirate copied' material. The last two decades, R&D funds have tended to be prioritized for research in molecular genetics and genomics with less funding for further development and establishment of selective breeding that has proved to give long term genetic gains. However, also for applying genomic information efficiently a selective breeding program is a prerequisite.

With interesting similarities to the ABS debate in the CBD, there seems to be little immediate value in breeding and breeding programmes. Previous studies have shown that the incentives for capitalizing on salmon breeding materials have been virtually non-existent, due to low roe prices and low profit for improved breeding material; a trend that does not seem likely to change in the near future (Olesen et al., 2007; Rosendal et al., 2006). Similarly, there seems to be little profit to be reaped from increased knowledge about and improvements of genetic resources and their traits, as has also been claimed in the ABS debate (Grajal, 1999). At the same time, it is hard to refute the great profits from biotechnology – from traditional breeding to genetic engineering – and there is a growing business interest in access to valuable genetic material (Laird & Wynberg, 2005). This seems paradoxical also with a view to the valuable good of faster growing and hence cheaper salmon, which is resulting from the breeding programs. Here also we see that the willingness to pay is small but the interest in access is paradoxically high. The problem is that bringing forth fast growing, disease free fish is relatively expensive, whereas the result can be copied at very low costs. This has led to a pressure towards profitability and privatisation in the aquaculture sector, including the public breeding programmes. However, the cost of maintaining a good, disease free product is relatively high and the question is whether the market can be expected to deliver this service, when there is such a high degree of uncertainty regarding profits. Due to the high fertility of aquatic species, aquaculture breeding programs have shown to give high benefit/cost ratios and tremendous value creation for the society. This is also the case for family based programs aiming for a broad and sustainable breeding goal with many traits. The paradox illustrates the challenge of securing policy goals of affordable access to genetic improvements in breeding and to stimulate sustainability and innovation in aquaculture. The alternative to the continued funding of public breeding programmes may portend forfeiting the normative ideal of providing improved breeding material on an affordable basis.

In general, aquaculture is experiencing pressure towards higher production efficiency and short term profits. Hence, actors face emerging difficulties pertaining to adequate funding for sustainable breeding programmes and affordable access to improved genetic material. Historically, aquaculture in India and Norway has mainly been based on public investments to increase production, develop and widely disseminate material to as many users as possible, rather than creating proprietary products. The same was true for the original objectives of the GIFT tilapia project. This illustrates the nature of breeding material as a public good. Greater involvement of private sector leads however to stronger need for legal protection of genetic material. As this keeps knowledge out of the public domain, it is perceived to have negative implications for aquaculture. In a study by Rosendal et al. (forthcoming) it was found similarities between Norway, India and the GIFT donors regarding their normative objective to maintain affordable access to improved breeding material. Moreover, a common concern among the actors interviewed was how to avoid the tendency towards monopolisation in a globalised market and how to maintain affordable access to aquatic breeding material. At the same time, the demand for profitability is undermining these goals. This may lead cod (and well as shrimp and carp) breeding programmes on a similar track as that of salmon and GIFT tilapia. A waiver of public control may seem to go against the interests and advice from both private and public actors in the aquaculture sector itself.

Market consolidations and privatisation are among the structural factors that the actors themselves recognize as most important in changing the ground rules within the salmon sector (Olesen et al., 2007). The privatisation and commercialisation can be expected to turn the breeding goals towards developing products for which there are economically viable markets rather than developing new products based on social, ecological and biological criteria (with e.g. disease resistance and fish welfare traits). This development has come a long way in the case of salmon (and tilapia), where those that were previously public collections and publicly funded breeding programmes and breeders' lines have now been privatised; similar trends can be expected in the case of farmed cod. The overall structural traits of the aquaculture sector also go a long way in explaining why the aquaculture sector is much less subject to ABS conflicts between developed and developing countries compared to the plant sector. While not engendering a North-South conflict, the basic interests in access to breeding material remains similar for plant and animal genetic resources. As a result of the structural developments leading to fewer and larger companies, access conflicts may be more likely to evolve between small and large scale actors in the sector rather than between countries.

The biology of breeding suggests that the real value lies in continuous upgrading and improvement, and patents are not useful for this as it freezes innovation. The cost and time of obtaining a patent along with the long protection period in patent law (twenty years) hardly promote rapid innovation in sectors where continuous upgrading in a biological dynamic system is the most viable and sustainable approach. Interestingly, neither of the two salmon breeding companies (AquaGen and Landcatch Natural Selection) that managed to map the QTL marker for IPN resistance have chosen to patent it. Probably, the costs involved with enforcing such patents are considered too high for these companies (even for AquaGen backed by a big international firm). Nevertheless, similar to agriculture and pharmacy, the structural changes within the aquaculture sector seem to be much more influential than biological traits in affecting actors' perceptions of need for access and protection. This also has implication for the broader international debate pertaining to the Nagoya Protocol on ABS and whether it needs to be supplemented by sector based treaties emulated to different types of genetic resources. As the structural traits of monopolization and globalisation are similar across the board (agriculture, pharmacy, aquaculture), that would suggest a reduced rationale for a sector approach to regulating international transactions with genetic resources.

## 9. Recommendation

Aquaculture is a source for food all around the world (FAO, 2009). Can it with its biotechnological development be sustainable on both short and long-term? As we have presented in this chapter there are several challenges that actors within the aquaculture sector is facing and decisions has to be made.

In the EU communication (2002) 'A strategy for the sustainable development of European aquaculture' it is emphasised that 'The fundamental issue is therefore the maintenance of competiveness, productivity, durability of the aquaculture sector. Further developments of the industry must take an approach where farming technologies, socio-economics, natural resources use and governance are all integrated so that sustainability can be achieved.' This is a very ambitious vision for the future and implies an integrated assessment of environmental, social, economic and legal issues. To do so we recommend that:

- Selective breeding programs with sufficiently low inbreeding rate are initiated to supply domesticated and genetically improved seed fit for a life in farm environment. Moreover, along with these programs there is also a need for breeding programs for farming in different environments for the most important farmed species.
- Breeding strategies towards broad and long terms goals should be included to ensure genetic variability and robust farm animals with good welfare. Initiatives for breeding for e.g. disease and parasite resistance are started up and improved to ensure sustainability of the industry. Application of molecular genetics (MAS and GS) may improve the efficiency of such initiatives. However, efficient application of MAS and GS require well organised selective breeding programs.
- Public support or cooperative ownership and organisation is necessary to promote the recommendations above. Economic support and training to establish lacking selective breeding schemes may for example be needed to apply and exploit powerful molecular techniques, and parallel funding and training are needed for development of local capacity within genetic engineering/biotechnology and selective breeding programs.
- Patent laws and practice should avoid too broad patents (e.g. of virus and bacteria) that hamper further innovation.
- Introduction of GMOs and products such as transgenic fish, DNA vaccines and GM vaccines need to involve application of precautionary approaches that include research on adverse effects by the inserted genes on animal health and welfare and on the environment. Moreover such introduction must also be followed with monitoring strategies for detection of unexpected effects.
- Consumers and public opinions and attitudes to new biotechnologies in aquaculture need to be identified together with studies on willingness to support and pay for e.g. improved health and welfare of farmed fish.
- Potential implications for the industry by introduction of biotechnology is important and need to be elaborated with the intention to find ways that the technology can stimulate sustainable innovations.

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## 11. Interviews

Interview with NN1, Ministry of Fisheries and Coastal Affairs, 26th August 2009.

Interview with NN2, Research Institute, 9th June 2009.

Interview with NN3, Breeding Company, 1st July 2009.

## 12. References

Animal Welfare Act. In: *GOVERNMENT.NO, Information from the Government and the Ministries.* 10.08.2011, Available from http://www.regjeringen.no/en/doc/laws/Acts/animal-welfare-act.html?id=571188

Aquagen (2010). QTL-rogn - dokumentert IPN-beskyttelse fra første dag. In: *AquaGen Kunnskapsbrev.* No.1. (2010), p. 1, 19.06.2011, Available from: http://aquagen.no/filestore/01-2010QTL-rogn-dokumentertIPN-beskyttelsefrafrstedag.pdf

Bentsen, H.B., & Gjerde, B. (1994). Design of fish breeding programs. *Proceedings of the 5th World Congress of Genetics Applied to Livestock Production*, Vol.19, pp. 353- 359, Guelph, Canada, August 1994.

Bentsen, H.B. & Olesen, I. (2002). Designing aquaculture mass selection programs to avoid high inbreeding rates. *Aquaculture*, Vol.204, pp. 349-359 .

Bergfjord, O.J. (2009). Risk perception and risk management in Norwegian aquaculture, *Journal of Risk Research,* Vol.12, No.1, pp.91-104.

Broom, D.M. (1986). Indicators of poor welfare. *British Veterinary Journal*, Vol.142, pp. 524–526.

Caffey, R.H., Kazmierczak, R.F., Romaire, R.P. & Avault, J.W. (1998). Indicators of aquaculture sustainability: a Delphi survey, *Book of Abstracts of The international triennial conference and exposition of the World Aquaculture Society, the National Shellfisheries Association and the Fish Culture Section of the American Fisheries Society*, pp.91, Las Vegas, USA, 1998.

CBD (2000). *Cartagena Protocol on Biosafety to the Convention on Biological Diversity*. (Montreal: Secretariat of the Convention on Biological Diversity). 16.12.2010, Available from http://bch.cbd.int/protocol/publications/cartagena-protocol-en.pdf

Devlin, R.H., Yesaki, T.Y., Donaldson, E.M., Du, S.J., Shao, J.D. & Hew, C.L. (1995). Production of germline transgenic Pacific salmonids with dramatically increased growth performance. *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 52, pp. 1376-1384.

European Commission (2002). *A strategy for the sustainable development of European aquaculture*. 29.4.2010, Available from http://ec.europa.eu/fisheries/cfp/aquaculture_processing/aquaculture/strategy_en.htm.

FAO, (2009). Bartley, D.M., Benzie, J.A.H. et al.: *The Use and Exchange of Aquatic Genetic Resources for Food and Agriculture.* CGRFA Background Study Paper No. 45 , FAO, Rome

Fleming, I.A. & Gross, M.R. (1992). Reproductive-behavior of hatchery and wild coho salmon (oncorhynchus-kisutch) - does it differ. *Aquaculture*, Vol.103, pp. 101-121.

Gaskell, G. & Bauer, M.W. (Eds.) (2001). *Biotechnology, 1996–2000: The years of controversies*, Science Museum Press, London

Gaskell, G., Allum, N. & Stares, S. (2003). *Europeans and Biotechnology in 2002*: *Eurobarometer 58.0.* A report to the EC Directorate General for Research from the project Life Sciences in European Society. March 21, 2003 (2nd edition).

Gillund, F., Kjølberg, K., Krayer von Krauss, M. & Myhr, A.I. (2008a). Do uncertainty analyses reveal uncertainties? Using the introduction of DNA vaccines to aquaculture as a case. *Science of the Total Environment* , Vol.407, pp. 185-196.

Gillund, F., Tonheim T., Seternes T., Dalmo R.A. & Myhr A.I. (2008b). DNA vaccination in aquaculture –Expert judgements of impact on environment and fish health, *Aquaculture*, Vol. 284, pp. 25-34.

Gillund, F. & Myhr, A.I. (2010). Perspectives on salmon feed: A deliberative assessment of several alternative feed resources. *Journal of Agricultural and Environmental Ethics,* Vol. 23, pp. 527-550.

Gjedrem, T., Robinson, N., Rye, M. (2011). The importance of selective breeding in aquaculture to meet future demands for animal protein: A review. *Aquaculture.* Submitted

Gjerde, B., Gjøen, H.M. & Villanueva, B. (1996). Optimum designs for fish breeding programmes with constrained inbreeding. Mass selection for a normally distributed trait. *Livestock Production Science*, Vol.47, pp. 57-72.

Gjøen, H.M. & Bentsen, H.B. (1997). Past, present and future of genetic improvement in salmon aquaculture, ICES Journal of Marine Science, Vol.54, pp. 1009-1014

GMO Compass (2009). Opposition decreasing or acceptance increasing?, 28.5.2011, Available from http://www.gmo-compass.org/eng/news/stories/415.an_overview_european_consumer_polls_attitudes_gmos.html

Grajal, A. (1999). Biodiversity and the Nation State: Regulating Access to Genetic Resources Limits Biodiversity Research in Developing Countries. *Conservation Biology,* Vol.13, No.4, pp. 6-10.

Hayes, B. & Andersen, Ø. (2005). Modern biotechnology in aquaculture. In: *Selection and Breeding Programmes,* T. Gjedrem (Ed.), pp. 301-317, Springer, ISBN -10 1-4020-3341-9, Dordrecht.

Haavind Vislie advokatfirma. (2008). Letter of 19 June to Norwegian competition authorities.

Hew, C.L. & Fletcher, G.L. (2002). The role of aquatic biotechnology in aquaculture. *Aquaculture*, Vol.197, pp. 191-204.

Holmenkollen Guidelines (1999). Holmekollen Guidelines for sustainable aquaculture 1997. In: *Sustainable Aquaculture,* N. Svennevig, H. Reinertsen, M. New (Eds.), pp. 343-347, Proceedings of the Second International Symposium on Sustainable Aquaculture: Food for the future? Oslo, Norway, November, 1997, AA. Balkema, Rotterdam/Brookfield

Hyperdictionary, (2003). *hyperdictionary.* Available from: http://www.hyperdictionary.com.

Huntingford, F.A., Adams, C., Braithwaite, V.A., Kadri, S., Pottinger, T.G., Sandøe, P. & Turnbull, J.F. (2006). Current issues in fish welfare. *Journal of Fish Biology*, Vol.68, pp. 332-372.

Johnsson, J.I., Petersson, E., Joensson, E., Bjoernsson, B.T. & Jaervi, T. (1996). Domestication and growth hormone alter antipredator behavior and growth patterns in juvenile brown trout, Salmo trutta. *Canadian Journal of Fisheries and Aquatic Sciences*, Vol.53, pp. 1546-1554

Kamara, M., Coff, C. & Wynne, B. (2006). *GMOs and Sustainability: Contested visions, routes and drivers*. Report prepared for the Danish Council of Ethics, Copenhagen.

Kapuscinski, A.R. & Brister. D. J. (2001). Genetic impacts of aquaculture. In: *Environmental Impacts of aquaculture*, K.D. Black (Ed.), pp. 128-153, Sheffield, UK, Sheffield Academic press.

Kibenge, F.S.B., Garate, O.N., Johnson, G., Arriagada, R., Kibenge, M.J.T. & Wadowska, D. (2001). Isolation and identification of infectious salmon anaemia virus (ISAV) from Coho salmon in Chile. *Diseases of Aquatic Organisms* , Vol.45, pp. 9–18.

Koester, V. (1997). The Biodiversity Convention Negotiation Process and Some Comments on the Outcome. *Environmental Policy and Law,* Vol. 27, No.3, pp. 175-192.

Kolstad, K., Heuch, P.A., Gjerde, B., Gjedrem, T. & Salte R. (2005). Genetic variation in resistance of Atlantic salmon (Salmo salar) to the salmon louse *Lepeophtheirus salmonis*. *Aquaculture,* Vol. 247, pp. 145-151.

Kvakkestad, V., Gillund, F., Kjølberg, K. & Vatn, A. (2007). Scientists' perspectives on the deliberate release of GM crops. *Environmental Values*, Vol.16, pp. 79-104.

Kwang, J. (2000). Fishing for vaccines. *Nature Biotechnology*, Vol.18, pp. 1145-1146.

Laird, S. & Wynberg, R. (2005). *The Commercial Use of Biodiversity: An Update on Current Trends in Demand for Access to Genetic Resources and Benefit-Sharing, and Industry Perspectives on ABS Policy and Implementation*. UNEP/CBD/WGABS/4/INF/5.

Le Curieux – Belfond, O., Vandelac, L., Caron, J. & Seralini, G.E. (2009). Factors to consider before production and commercialization of aquatic genetically modified organisms: the case of transgenic salmon. *Environmental Science and Policy*, Vol.12, pp. 170-189.

Lund, V., Mejdell, C., Röcklinsberg, H., Anthony, R. & Håstein, T. (2007). Expanding the moral circle: farmed fish as objects of moral concern. *Diseases of Aquatic Organisms*, Vol.75, pp. 109-118.

Marine Harvest. (2011). *Salmon, a small protein source, but a great alternative in the global market place*. Presentation held by A. Aarskog at the North Atlantic Seafood Conference in Oslo 3.3. 2011, Available from http://hugin.info/209/R/1494191/430048.pdf

Mazur, C.F. & Iwama, G.K. (1993). Effect of handling and stocking density on hematocrit, plasma-cortisol, and survival in wild and hatchery-reared chinook salmon (oncorhynchus-tshawytscha). *Aquaculture,* Vol.112, pp. 291-299

McGinnity, P., Stone, C., Taggart, J.B. Cooke, D., Cotter, D., Hynes, R. et al. (1997). Genetic impact of escaped farmed Atlantic salmon (Salmo salar L.) on native populations: use of DNA profiling to assess freshwater performance of wild, farmed, and hybrid progeny in a natural river environment. *ICES Journal of Marine Science,* Vol.54, pp. 998-1008

Melamed, P., Gong, Z., Fletcher, G. & Hew, C.L. (2002). The potential impact of modern biotechnology on fish aquaculture. *Aquaculture*, Vol. 204, pp. 255-269.

Metcalfe, N.B., Valdimarsson, S.K. & Morgan, I.J. (2003). The relative roles of domestication, rearing environment, prior residence and body size in deciding territorial contests between hatchery and wild juvenile salmon. *Journal of Applied Ecology*, Vol.40, pp. 535-544.

Meuwissen, T.H.E., Hayes, B.J. & Goddard M.E. (2001). Prediction of total genetic value using genome-wide dense marker maps. *Genetics,* Vol.157, pp. 1819-1829.

Moen T., Baranski M., Sonesson A.K. & Kjøglum, S. (2009). Confirmation and fine-mapping of a major QTL for resistance to infectious pancreatic necrosis in Atlantic salmon (Salmo salar): population-level associations between markers and trait. *BMC GENOMICS,* Vol.10, pp. 368.

Myhr, A.I. & Traavik, T. (2011). *Genetically Engineered Virus Vaccine Vectors: Environmental Risk Management Challenges*, In: Genetic Engineering, InTech, ISBN 978-953-307-671-3.

Niiler, E. (2000). FOA researchers consider first transgenic fish. *Nature Biotechnology*, Vol. 18, pp. 143.

Norwegian Ministry of Fisheries and Costal Affairs (2009). *Strategi for en miljømessig bærekraftig havbruksnæring*. 10.07.2009, Available from http://www.regjeringen.no/...strategier.../strategi-for-en-miljomessig-barekraftig-.html.

Olesen, I., Groen, A.F. & Gjerde, B. (2000). Definition of animal breeding goals for sustainable production systems. *Journal of Animal Science*, Vol.78, pp. 570-582.

Olesen, I., Rosendal, G.K., Bentsen, H.B., Tvedt, M.W. & Bryde, M. (2007). Access to and protection of aquaculture genetic resources - Strategies and regulations. *Aquaculture.* Vol.272, No.1, pp. S47-S61

Olesen, I., Alfnes, F., Røra, M., Navrud, S. & Kolstad, K. (2010). Eliciting consumers' willingness to pay for organic and welfare labelled salmon by a non-hypothetical choice experiment. *Livestock Science*, Vol.127, pp. 218-226.

Olesen, I., Myhr, A.I. & Rosendal, G.K. (2011). Sustainable aquaculture: are we getting there? Ethical perspectives on salmon farming. *Journal of Agricultural and Environmental Ethics.* Vol.24, No. 4, pp. 381-408.

Petersson, E. & Järvi, T. (2006). Anti-predator response in wild and sea-ranched brown trout and their crosses. *Aquaculture*, Vol.253, pp. 218-228.

Ponzoni, R.W., Khaw. H.L. & Yee, H.Y. (2010). GIFT: the story since leaving ICLARM (now WorldFish Centre) – socioeconomic, access and benefit sharing and dissemination aspects. *FNI Report*, 14/2010, Oslo, Norway

Ramanna Pathak, A. (fortcoming) Balancing biodiversity, access to genetic resources and profits in India's shrimp sector.

Rauw, W.M., Kanis, E., Noordhuizen-Stassen, E.N. & Grommers, F.J. (1998). Undesirable side effects of selection for high production efficiency in farm animals. A review. *Livestock Production Science*, Vol.56, pp. 15-33.

Refstie, T. & Gjedrem, T. (2005). Chromosome Engineering. In *selection and Breeding, Programmes, T.* Gjedrem (Ed.), pp 287-299, Springer, ISBN -10 1-4020-3341-9, Dordrecht

Robinson, N. (2002). Techniques for advanced genetic improvement of fin fish and shellfish in aquaculture. *Report on an NRE scientific exchange visit to aquaculture and marine science institute in Scotland and Norway*, September 2002. Australia, Victorian Institute of Animal Science

Romøren, K. (2003). Liposome- and Chitosan-based formulations used for gene delivery to fish: -*in vivo* and *in vitro* studies of possibilities and limitations. Ph.D. dissertation, ISSN 1501-7710. Faculty of Mathematics and Natural Sciences, Department of Pharmaceutics, School of Pharmacy, University of Oslo, Norway

Rosendal, G.K. (2000). *The Convention on Biological Diversity and Developing Countries.* Dordrecht: Kluwer Academic Publishers

Rosendal, G. K., Olesen, I., Bentsen, H.B., Walløe Tvedt, M. & Bryde, M. (2006). Access to and legal protection of aquaculture genetic resources – Norwegian perspectives. *Journal of World Intellectual Property,* Vol. 9, No.4, pp. 392-412.

Rosendal, G.K. (2006). Regulating the Use of Genetic Resources – Between International Authorities. *European Environment*, Vol.16, No. 5, pp. 265-277.

Ruzzante, D.E. (1994). Domestication effects on aggressive and schooling behavior in fish. *Aquaculture*, Vol.120, pp. 1-24.

SalmoBreed. (2011). SalmoBreed AS har identifisert genetisk markør for sykdommen pancrease disease (PD). In: N*yhetsbrev fra SalmoBreed*. Vol.7, No.3, (June 2011), p.1, 19.06.2011, Available from: http://www.salmobreed.no/files/Nyhetsbrev/nyhetsbrev_2011/2011_3_nyhetsbrev_SalmoBreed_-_Kopi.pdf

Sandøe; P. & Holtug, N. (1998). Ethical aspects of gene and biotechnology. *Acta Agriculturae Scandinavia, Section A: Animal Science,* Suppl. 29, pp. 51-58.

Sandøe, P. & Christensen, S.B. (2008). *Ethics of animal use*. Blackwell Publishing, ISBN 978-1-4051-5120-7, Oxford, UK

Sonesson, A.K., Meuwissen, T.H.E. & Goddard, M.E. (2010). The use of communal rearing of families and DNA pooling in aquaculture genomic selection schemes. *Genetics Selection Evolution,* Vol.42, No.41, pp. 9

Thompson, G.D. & Kidwell, J. (1998). Explaining the choice of organic produce: Cosmetic defects, prices, and consumer preferences. *American Journal of Agriculture Economics,* Vol.80, pp. 277–287.

Traxler, G.S., Anderson, E., LaPatra, S.E., Richard, J., Shewmaker, B. & Kurath, G. (1999). Naked DNA vaccination of Atlantic salmon, *Salmon salar* against IHNV. *Diseases of Aquatic Organisms*, Vol. 38, pp. 183–190.

Turnbull, J.F., Adams, C.E., Richards, R.H. & Robertson, D.A. (1998). Attack site and resultant damage during aggressive encounters in Atlantic salmon (Salmo salar L.) parr. *Aquaculture*, Vol.159, pp. 345-353.

Verhoog, H. (2001). The intrinsic value of animals: its implementation in governmental regulations in the Netherlands and its implications for plants. *Proceedings of Ifgene* *workshop Intrinsic value and integrity of plants in the context of GE*. pp. 15-18, Dornach, Switzerland, May 9-11, 2001

Walls, J., Tee Rogers-Hayden, A.M. & O'Riordan, T. (2005). 'Seeking citizens' views on GM crops: Experiences from the United Kingdom, Australia and New Zealand', *Environment*, Vol.47, No.7, pp. 23–36

WCED (1987). *Our Common Future*. Oxford: Oxford University Press.

White Paper. (2005). (Stortingsmelding) *Den blå åker (The blue field)* No. 19. 2004-2005.

White Paper. (2009). (Stortingsmelding) *Interesser, ansvar og muligheter. Hovedlinjer i norsk utenrikspolitikk (Interests, responsibilities and options. Main avenues in Norwegian foreign politics)* No.15. 2008-2009.

Yue, C., Alfnes, F. & Jensen, H.H. (2009). Discounting spotted apples: Investigating consumers' willingness to accept cosmetic damage in an organic product. *Journal of Agriculture & Applied Economics* Vol.41, pp. 1-18