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ENVIRONMENTAL EFFECTS OF COD FARMING

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ENVIRONMENTAL EFFECTS OF COD FARMING

Cod farming is well on the way to becoming a new industry. In the course of three years, production of farmed cod has risen by a factor of ten, from 946 tonnes in 2003 to more than 10,000 tonnes in 2006. The environmental challenges presented by the rise in production are formidable, and will have to be taken seriously before cod farming goes much further. It is important that we should learn from salmon farming, where we have always lagged behind in carrying out essential environmental studies. As far as cod are concerned, spawning in sea-cages, escapes and genetic interactions with wild cod, disease and the spread of pathogenic organisms are all potential problems that need to be studied now.

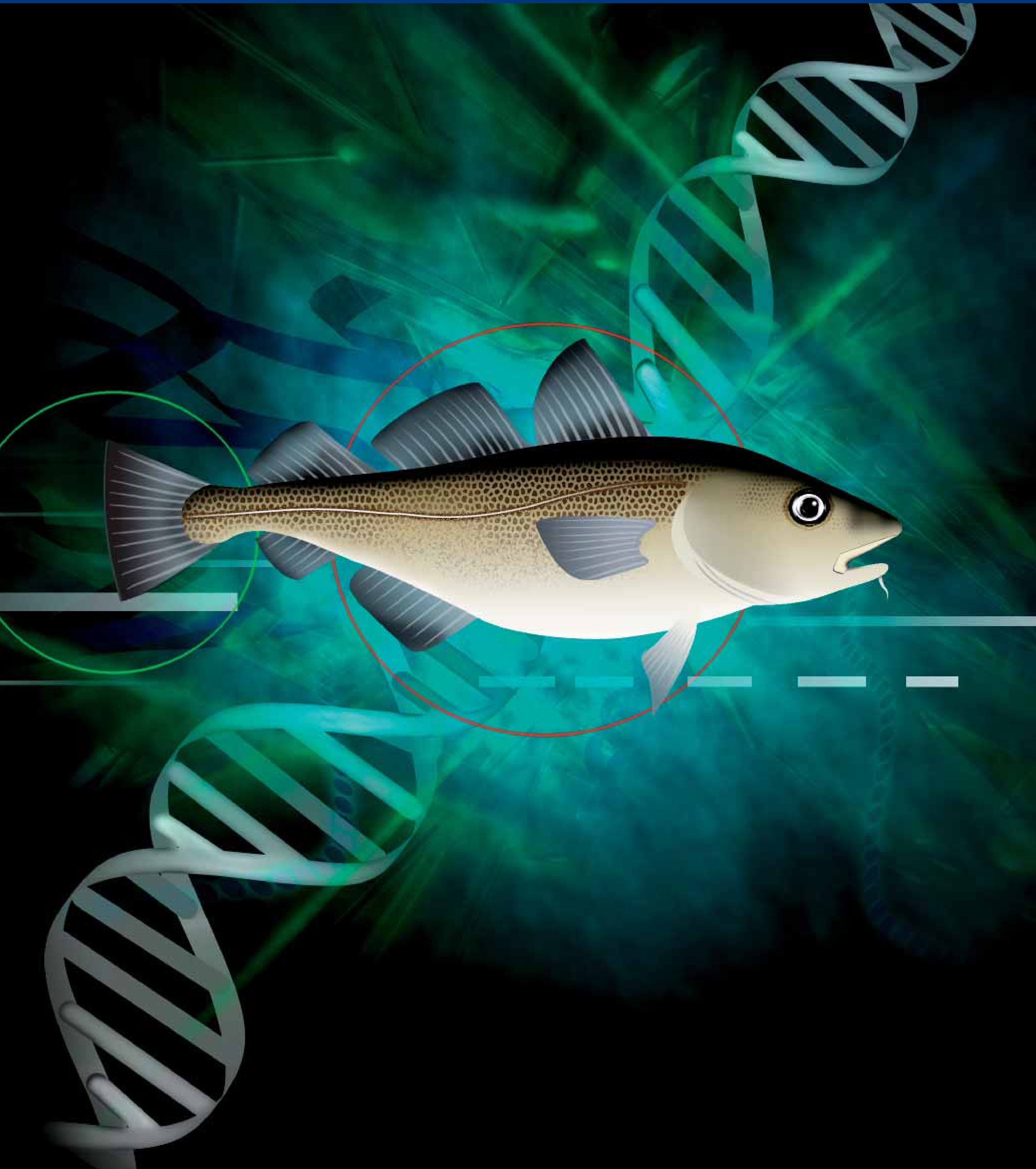
Cod farming has a long tradition in Norway, going all the way back to the end of the 1880s, when hundreds of millions of newly hatched cod larvae were released off the coast of southern Norway, the USA and Canada. This activity continued for almost 90 years, and was brought to an end without any effects of these cultivation measures ever being documented. Nevertheless, these trials formed the basis for the start of marine fish farming. In the 1970s, experiments were restarted using cod juveniles, and a great deal of effort was put into understanding the cod life cycle. Parallel trials were carried out in the laboratory and the field, and in 1983 Institute of Marine Research scientists managed to produce 70,000 cod juveniles in an enclosed natural pond at the Austevoll Research Station. This laid the foundations for commercial cod farming in Norway, although many years were still to pass before the research results could be commercialised

The Institute of Marine Research (IMR) has played an important role in the development of cod farming, and at the beginning of the 90s, scientists at its Matre Research Station showed that sexual maturation in cod can be halted or delayed by controlling light conditions. This was the basis for the further development of cod as a farmed species, since all fish normally become sexually mature two years after they hatch. Early sexual maturation and spawning in sea-cages are both a financial problem for the farmer and a potential environmental problem that can result in the transmission of genetic material to wild cod.

Disease was another problem, but the IMR's production of juveniles made it possible to do research on potential solutions. Vaccines were tested and improved in collaboration with pharmaceutical companies. It soon became obvious that vaccines and other methods of treatment would have to be specially adapted to cod if they were to have satisfactory effects.

In parallel with laying the foundations of commercial cod farming, for many years the Institute of Marine Research has been carrying out ecological and genetic studies of our wild cod stocks. This has provided knowledge of importance to our ability to evaluate the effects of cod farming.

In 2006, 11.3 million cod juveniles were released in sea-cages, and 11,087 tonnes of farmed cod were produced (including 703 tonnes produced from wild-caught fry) in Norway (interim figures from the Directorate of Fisheries). Significant resources are being put into the development of efficient methods of production of high-quality juveniles and cost-effective fish for human consumption. The Norwegian Institute of Fisheries and Aquaculture Research in Tromsø is responsible for a cod breeding programme, while the Institute of Marine Research has overall responsibility for studying the environmental effects of cod farming.



ESCAPED COD:
GENETIC EFFECTS ON WILD STOCKS?

Genetic effects on wild stocks are among the most important environmental challenges facing cod farming today.

Cod behave differently from salmon, and are more likely to escape if they find a hole in the sea-cage netting. Although the scope of cod farming is still very limited, serious escapes have already been reported, including 290,000 cod that escaped in 2006. This is an extremely high figure in view of the relatively low level of production.

Several factors suggest that we face major challenges in cod farming. Coastal cod have their spawning and nursery grounds in the same areas as cod farms, and there are no barriers between them. Under normal conditions, cod become sexually mature after two years in fish farms, and genetic effects may be produced if cod escape or if fertilised eggs are released from sea-cages.

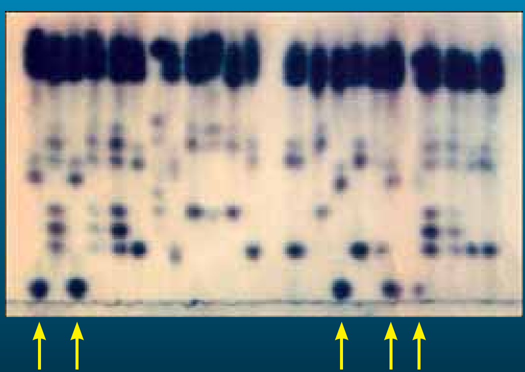
We have a good basis for evaluating the genetic effects of cod farming, since genetic studies of wild cod have been performed since the sixties. Since 2002, a large-scale survey of the genetic structure of coastal cod along the whole of the coast of Norway has been carried out. Almost 11,000 samples have been collected from 106 sites on the coast. There are wide genetic variations between coastal cod from different areas – particularly when we compare cod from the north and south of the country.

A number of methods are available to identify genetic differences between the northeast arctic cod – known as ”skrei” in Norwegian – and coastal cod. Recent analyses in the *Pan*I system have found major genetic differences between the two groups. Differences have also been found in the haemoglobin system and in three DNA microsatellites.

As part of the PUSH sea-ranching programme, more than 200,000 genetically tagged cod were released (see fact box) at three sites in Hordaland; Heimarkspollen in Austevoll), Masfjorden and Øygarden. The releases resulted in a rise in the frequency of the marker gene in the release areas. IMR has now re-established a stock of genetically tagged cod, and in 2006 a controlled experiment to study the effects of spawning in sea-cages was carried out.

GENETICALLY TAGGED COD

Genetically tagged cod have been bred with a unique variant of the protein-coding gene GPI-1 (*GPI-1 *30/30*). Such variants can easily be identified by means of a technique known as protein electrophoresis.



Protein electrophoresis: each vertical stripe is an individual, and the arrows identify individuals genetically tagged individuals.

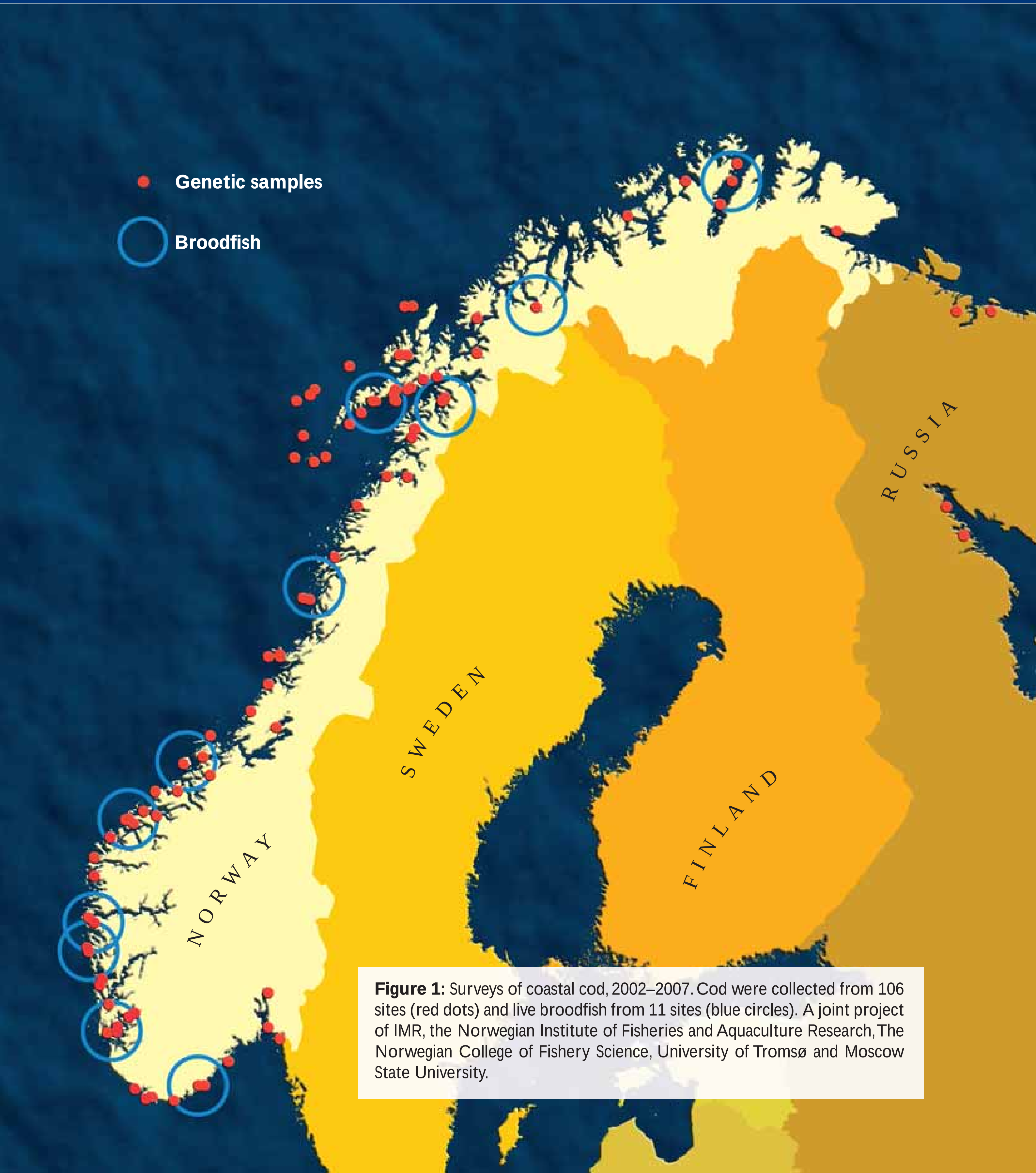


Figure 1: Surveys of coastal cod, 2002–2007. Cod were collected from 106 sites (red dots) and live broodfish from 11 sites (blue circles). A joint project of IMR, the Norwegian Institute of Fisheries and Aquaculture Research, The Norwegian College of Fishery Science, University of Tromsø and Moscow State University.

SPAWNING IN SEA-CAGES

Under normal conditions of growth, most farmed cod will become sexually mature at two years of age, and under good growth conditions some farmed cod can become sexually mature when they are only one year old.

Farmed cod become sexually mature earlier than similar wild cod, which usually mature when they are between three and eight years old, depending on growth conditions, among other factors. The good food availability and rapid growth rates are probably the cause of early sexual maturation in farmed cod. As well as representing one of the most serious welfare problems in cod farming, resulting in high death rates, early maturation can mean that sexually mature farmed cod may pose a genetic threat to wild cod stocks. This can happen if they escape from sea-cages or as a result of successful spawning and fertilisation of eggs in the cages. Farmed cod produce large quantities of eggs, and a large stock of spawning farmed cod on the coast could produce a large proportion of fertilised eggs in comparison with wild fish.

In order to obtain more data on the effects of spawning in sea-cages, in 2006 IMR carried out an experiment in which a broodstock group of genetically tagged cod was released into a semi-enclosed fjord system, Heimarkspollen in Austevoll (80 m^3). Wild cod also spawn in this system. Using genetically tagged broodstock enables us to identify the offspring of the farmed cod, and thus to quantify how many offspring were the result of natural spawning in the sea-cage.

The experiment showed that at the beginning of April 2006, 25% of the cod larvae in the water column came from the genetically tagged farmed cod. By the end of April, the cod larvae had dispersed widely, even out of the semi-enclosed system. Rather more than one percent of the cod larvae that were found 8 km from the spawning sea-cage had the genetic tag.

A large-scale spawning experiment was repeated in 2007, using two sea-cages for spawning. This demonstrated that 35% of the larvae in Heimarkspollen in mid-April were the offspring of spawning caged fish. The larvae had dispersed out of Heimarkspollen, and 10–19% of the larvae that were found in the adjacent fjord system were genetically tagged.

Farmed cod become sexually mature earlier than wild cod, and may pose a genetic threat to wild cod populations.

These experiments show that we can find the offspring in nature of cod that have spawned in sea-cages, but more studies are needed to determine what proportion of these fry survive to adulthood.

DELAYED SEXUAL MATURATION AND STERILE FISH.

To date, research has shown that controlling light conditions in sea-cages can postpone sexual maturation in farmed cod, but cannot completely halt the process. Just as in salmon, the use of light can postpone first maturation and increase weight in cod. In tanks, the sexual maturation of cod can be postponed to at least three years of age by controlling light conditions, but so far, in sea-cages, it has only been possible to postpone maturation by four to six months, so that it takes place in the summer instead of during the natural spawning season between February and April.

It is still uncertain whether "light-controlled" cod actually release eggs in the sea-cages when they become sexually mature in the summer months, and whether any such eggs will be fertilised and produce viable offspring. High summer temperatures can prevent cod from spawning, but this effect has yet to be studied.

Even if controlled lighting conditions are capable of improving production results for cod farmers, and possibly also preventing or reducing releases of fertilised cod eggs from sea-cages, light control will not prevent escaped cod from spawning. Cod seem to escape easily from sea-cages, and there may therefore be a need for alternative techniques for preventing sexual maturation and spawning in farmed cod. Measures might include production of sterile cod, for example by triploidisation, a term which means that the fish have three sets of chromosomes, two from the mother and one from the father. Triploid fish are normally completely sterile. Triploid fish are usually produced by exposing the eggs to pressure shock immediately after fertilisation. Recent experiments carried out in Canada have shown that this technique can also be utilised in cod, and individuals of this species are being followed up in order to check whether they are completely sterile.

However, it is not known whether triploid cod will manage as well as normal cod in fish farms. Triploid salmon appear to be less robust than normal salmon, and under special environmental conditions they may develop more deformities and grow more slowly than normal fish. Before we start full commercial production of triploid cod, we should therefore study their production characteristics, health and welfare under a range of environmental conditions.

Photo: Norwegian Seafood Export Council

SPREAD OF PATHOGENIC ORGANISMS

The spread of pathogens from fish farms to wild stocks could represent a significant challenge to the environment. The salmon louse problem, for example, has shown that disease agents spread in this way can have serious negative effects on wild stocks. Special care needs to be taken when fish farms are located in important spawning and nursery grounds for wild fish. Some diseases can be spread via eggs, and if such disease situations arise and the cod spawn, there is a danger of spread of disease. In such cases, a natural measure would be premature slaughter of the fish.

Bacteria and viruses

Different pathogenic micro-organisms have varying survivability in open water. Free virus particles are more or less inactivated by UV radiation from the sun, while viruses bound to organic particles are more capable of stabilisation. There are also major differences in survival times between different types of virus, since viruses have been “constructed” in very different ways by nature.

Most bacteria that are capable of causing disease in fish are what we call opportunistic pathogens. They are capable of surviving in water for long periods of time and of reproducing without their hosts. In about 1990, several studies of the ability of bacteria to tolerate starvation were published, and they concluded that many bacteria can survive for long periods of time, both in water and in sediments. Today, we know that the picture is more complex than that. The turnover of bacteria in nature can be high, which means that bacteria that do not reproduce rapidly can fall in number. So far, most of the bacteria that have caused disease in fish have been opportunistic. Such bacteria possess a much wider set of survival strategies than we find in viruses or more specialised pathogenic bacteria, which can only survive in a host. Opportunists are not only capable of surviving independently of a host species but may even form part of the host’s normal flora. This means that they are present in healthy individuals and only trigger an outbreak of illness when the host is weakened, for example as a result of stress caused by rapid changes in temperature or extreme hunger. Many bacteria of this sort, such as the *Vibrio* types and atypical furunculosis bacteria, have been found in several species of fish.

During the past few years, the bacterial disease known as francisellosis has affected a number of cod farms. This disease is caused by the recently discovered bacterium *Francisella piscicida*, which lives inside the cells of the fish. This can make both treatment and prevention of this disease difficult, and at present there are no commercially available vaccines. Francisellosis develops slowly, and a fish

can be a carrier of the disease without this being obvious. Cod that become sick grow more slowly and gradually develop visible injuries on their skin and inner organs, particularly the spleen and kidneys. Unpublished data from a cooperative project between the University of Bergen and IMR suggest that the *Francisella* bacterium and the disease it causes are fairly widespread in wild cod, at least along the coast of southern Norway. An epidemic outbreak of this disease has also been observed in the Skagerrak/Kattegat. Since both the coastal current and large numbers of farmed cod are transported in a northerly direction, it is likely that *Francisella* infections will be spread by water, wild fish and farmed fish.

In 2006, nodavirus, which is a well-known problem in halibut farming in Norway, has also hit farmed cod on three occasions. In general, juveniles are most vulnerable, developing the disease known as Viral Nervous Necrosis (VNN), which often has an extremely high mortality rate. The virus is known to be spread vertically, for example from the mother via her eggs to larvae and fry. Since farmed cod often spawn in sea-cages, infections caused by viruses that spread vertically are yet another threat to the environment, in addition to their potential for having genetic impacts. We still know far too little about the extent of the hazard of infection when cod sea-cages are located in important spawning grounds for wild fish, or about the hazard to wild fish in general or to other farmed fish. Studies on wild fish suggest that nodavirus infections are common. Since cod broodfish are often wild-caught, it is likely that fish used as broodstock have been virus carriers and thus may have contributed to the spread of disease. Virus carriers have also been found in other species of marine fish off the coast of Norway, but it is still unclear whether different species of fish are infected by different types of nodavirus. In any assessment of the environmental effects of cod farming, a survey of types of nodavirus would be an important first step towards a better understanding of the modes of infection and spread of the virus.

Another important marine fish virus that is capable of causing problems is the rabdovirus that causes the serious disease Viral Haemorrhagic Septicaemia (VHS) in salmonids. VHS is classified as an "exotic" disease, i.e. one that is not normally found in Norway. It is therefore a serious matter for a fish farmer to have the virus identified, since this will mean the slaughter of his stock and the closing of his farm. Only one type of VHS virus has been identified in Norway, but related virus types have been found in wild cod in the North Sea. Several studies have suggested that VHSV like viruses are common in several species of wild fish. However, it has proved difficult to experimentally

Photo: Norwegian Seafood Export Council

infect marine fish with VHS virus and cause clinical disease. For this reason, it is not certain whether the VHS virus is capable of being transmitted between marine fish species and farmed salmonids. Marine isolates of the VHS virus are genetically different from those that produce disease in salmonids, and different viruses may occur that attack different species of fish. It is therefore important to establish whether VHS infections can be transmitted between salmonids and marine species.

The infectious pancreatic necrosis virus (IPNV) also affects a wide range of hosts. It is important in salmon, but has also caused mortality in halibut and turbot farming. We know little about these viruses in wild fish, but it is not unlikely that they are widespread in wild fish stocks, perhaps including cod.

The risk of infections spreading from farmed fish to wild stocks is greatest in areas with high concentrations of fish farms. In such cases, it is important to protect the most important spawning grounds – such as Lofoten – from cod farming.
Et annet viktig marint fiskevirus som kan skape problemer, er rabdoviruset, som forårsaker den alvorlige laksesykdommen viral haemorragisk septikemi (VHS). Den er klassifisert som en eksotisk sykdom, dvs. en sykdom som normalt ikke finnes i Norge. Derfor er det alvorlig for en oppdretter å få påvist viruset, som vil medføre utslakting og båndlegging av anlegget.

Parasites

We know of more than 100 different parasites in cod. Some of these are likely to cause problems in cod farming. In general, parasites with direct transmission, i.e. those without intermediate hosts, are likely to cause the most serious problems. Such parasites find good living conditions in systems that have high concentrations of hosts, as is normal in fish farming. Of the many parasites that are known to infect cod, at least 22 species are directly transmitted (protists, *Gyrodactylus* and copepods) and have been found in cod in Norway. Some of these have already caused problems for cod farmers (*Trichodina* spp., *Gyrodactylus* spp., *Ichthyobodo* spp., *Caligus elongatus*).

Most of the larger parasites that have more complex life cycles with intermediate hosts will cause fewer

problems. Such parasites can enter fish farms with natural zooplankton used as feed. Experience from salmon farming shows that myxosporideans, a special group of parasites with intermediate hosts, may cause problems. Bristle-worms release quantities of spores that can infect fish, while the worms themselves are infected by spores released by the fish. This can result in a local cycle of mutual infection. In 2002, a hitherto unknown myxosporidean (*Parvicapsula*) was identified as the cause of death of farmed salmon, and this parasite has caused significant problems locally, particularly in northern Norway. Cod hosts seven known species of myxosporidea that may cause problems in aquaculture.

It is important to note that many of the parasites that infect cod, have different degrees of host specificity, which are often not known in detail. Some of them parasitize most species of bony fish, others only gadoids, and some possibly only cod.

Problems caused by parasite attacks and the spread of parasites from fish arms are of different types:

1) Increased local infection pressures: wild fish acquire more parasites, and possibly disease (e.g. salmon lice)
2) Transports of farmed fish may introduce new types of parasites (e.g. *Gyrodactylus* for salmon)
3) Aquaculture represents an environment where more virulent parasite strains may evolve (e.g. IPNV in salmon)
4) Environmental effects of treatment (e.g. delousing)
5) Environmental effects due to altered behaviour in wild fish, birds, seals, etc: attracted by fish farms and spread their own parasites (e.g. black spot disease and seabirds).

At present, we know too little about the occurrence of parasites or possible strains of these in cod to be able to satisfactorily evaluate such environmental effects of aquaculture. Our knowledge of the parasitic fauna of wild cod is so limited that any newly introduced species or strains of parasites most likely would be registered as native and hence passes undetected.

Photo: Norwegian Seafood Export Council

Lice

The salmon louse has become a familiar concept to most people in the wake of the problems that this parasite has caused the aquaculture industry. It is less well known that the salmon louse has a number of relatives, and that most species of fish have their "own" lice. In cod farming, two species are particularly liable to cause problems; the cod louse (*Caligus curtus*) and the sea louse (*Caligus elongatus*). Cod lice are found on cod and some other gadoids such as ling, pollack, saithe and tusk, while the sea louse is a generalist that has been found on more than 80 species of fish from several different families.

A significant proportion of the salmon louse larvae found today in the sea have been produced by lice that infest farmed salmon in sea-cages. Wild salmonids are therefore exposed to a much higher infection pressure that they would have been in the absence of aquaculture. The question is whether the same thing will happen with lice on farmed cod. Large-scale cod farming may well increase infection pressure on wild fish, and there will be far more suitable hosts for cod lice than for salmon lice outside the sea-cages.

It has been shown that salmon lice can transmit viruses between fish. We know little about whether cod lice or sea lice are capable of acting as disease carriers, but since these are more inclined to jump from one host to another than salmon lice, and since sea-cages often attract wild cod and other gadoids, the potential for spread would appear to be greater.

The incidence, ecology and behaviour of cod and sea lice have been little studied, and it is difficult to say what will happen in the future. Decisive factors will be whether lice infect cod in sea-cages and do well there, and whether the offspring of lice from farmed cod contribute to increased infection pressure on wild fish and other farmed fish. If we are to be able to say anything more about the consequences of cod farming for the spread of lice, research will have to be done on these two species in the next few years. First and foremost, it will be important to clarify whether fish in sea-cages become infected, and if so, how common such infections are, and just how the fish become infected. Do fully grown lice swim through the net and attach themselves to the fish, or do they grow up together with the fish in the sea-cage? Fish farms will also need to be monitored and data gathered, so that we can detect temporary changes in the infections.

It is of particular importance to obtain a better understanding of the normal situation in the sea and in fish farms before cod farming becomes widespread, so that it will be possible to detect any effects of farming. Moreover, such efforts must be made now; if we wait any longer it will be too late. Until we are in possession of this knowledge, a good strategy would be to avoid locating cod farms in the most important cod spawning grounds.

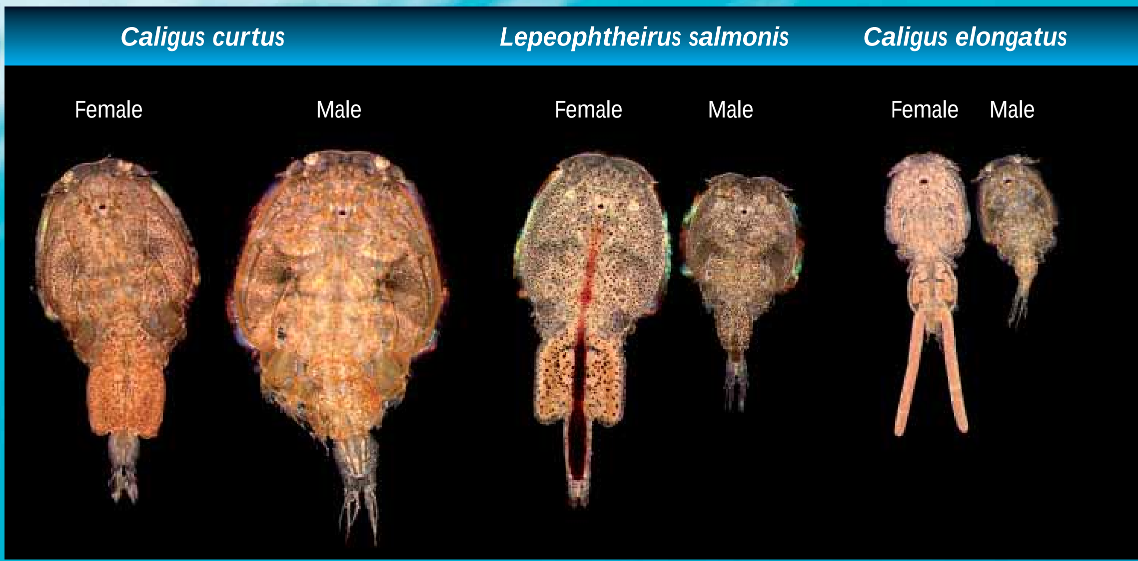


Figure 2. From left: cod louse (*Caligus curtus*), salmon louse (*Lepeoptheirus salmonis*) and sea louse (*Caligus elongatus*). Female salmon lice and cod lice are about 1 cm in length, and the photo illustrates the approximate relative sizes of the lice.

THE WAY AHEAD

Cod farming is expanding at an annual rate of about 20–25 percent, and finding solutions to the most important environmental challenges represented by this growing industry is a matter of urgency.

In the course of 2007, the IMR will complete a report on the genetic structure of coastal cod for the Ministry of Fisheries and Coastal Affairs. This report will form the basis for the future management of cod farming, as far as selection of farm sites and broodstock, etc., are concerned.

A continuation of the project on genetically tagged cod will provide answers regarding the environmental impact of farmed cod that spawn in sea-cages, and form the basis of management measures aimed at protecting valuable wild cod stocks and important spawning grounds.

It is obvious that efforts to prevent cod escapes must be intensified. But since cod can "escape" by natural spawning, research that aims to produce a sterile cod should be given priority. Research is under way on this topic, but efforts need to be intensified and should incorporate all aspects, such as efficient methods of sterilisation, fish welfare and consumer acceptance.

It is essential to obtain a better understanding of the normal situation for certain pathogens in the sea and in fish farms before cod farming becomes widespread, so that any effects of farming can be measured. Baseline levels of certain parasites, bacteria and viruses should therefore be identified and monitored systematically in a selection of stocks with different degrees of exposure to fish farms. Until we are in possession of this knowledge, a good strategy would be to avoid locating cod farms in the most important cod spawning grounds or areas with vulnerable cod stocks.

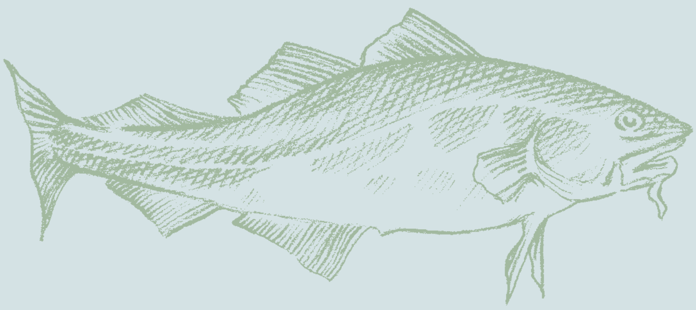


Photo: Norwegian Seafood Export Council

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