FARMING COD: PUTTING THE PRESSURE ON, AND TURNING UP THE HEAT?

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Over a period of 45 years, Norwegian aquaculture has developed from being a 'back-yard' venture to a modern, internationally competitive industry that exports its products to worldwide markets. Production (over 800 000t in 2008) is dominated by Atlantic salmon (*Salmo salar*)(ca. 85%) and rainbow trout (*Oncorhynchus mykiss*)(ca. 10%) but there is also some farming of Atlantic cod (*Gadus morhua*), blue mussel (*Mytilus edulis*) and a handful of other species (Fig. 1). The collapse of wild stocks of Atlantic cod off the eastern seaboard of Canada during the 1980ies, which led to a moratorium on cod fisheries in 1992, sounded a warning bell to North European governments already facing declining catches of cod from the North Sea and elsewhere. Gloomy prospects of declining stocks stimulated interest in the development of Atlantic cod farming in the mid-1980ies. Norway and other northern-hemisphere countries instigated research into the intensive production of this species in an attempt to repeat the success of the salmon farming industry.

A bumpy ride for cod farmers

Following initial efforts directed towards cod culture undertaken some 25 years ago interest soon waned and then remained dormant for a few years, but interest in farming cod increased again around the turn of the century. Over the last 10 years or so cod culture has developed in Norway and elsewhere: Canada, Iceland, United States and United Kingdom. By 2005 Norway, Canada, USA and Iceland had established selective breeding programmes to advance the domestication of Atlantic cod.

Following several early setbacks, intensive culture methods and practices gradually improved making a small supply of farmed cod available to international markets. This raised hopes of a rapid expansion, based partly on the assumptions that low fishing quotas and continued reduced supplies of wild fish would give a high market price. A high market price for the finished product was needed because of the high costs involved in producing farmed cod. The initial expectations were not met, and warning lights of commercial troubles ahead started to flash. Falling prices for wild-caught cod left cod farmers facing unforeseen competition, and this resulted in decreasing profits and an increasing number of financially-distressed cod aquaculture companies.

Despite its problems, the cod farming industry has overcome some important production bottlenecks, including those related to unpredictable and inconsistent supplies of eggs and juveniles. As such, the industry has the potential for developing stable production to complement a seasonal commercial fishery. In particular, farmed cod could satisfy the demand for a fresh product at times of the year when limited supplies of wild cod are available and prices are high. If consumers were prepared to pay a premium price for farmed cod at certain times of the year this would offset the high costs of production.

Not all doom and gloom, but…

Prior to the economic turmoil in the cod farming industry, the focus was on biological and technological challenges, such as egg and larval production, the development of technologies for production of live feeds,

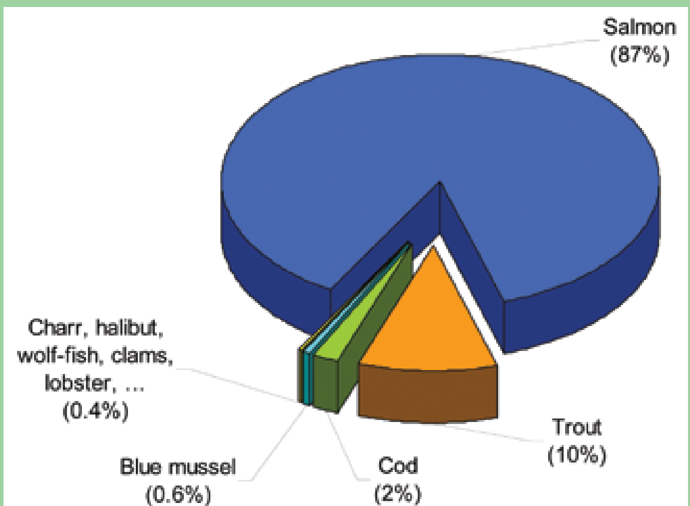

Figure 1. Production (as % of total production) of the major aquaculture species in Norway in 2008 (Data: Norwegian Directorate of Fisheries, 2009).

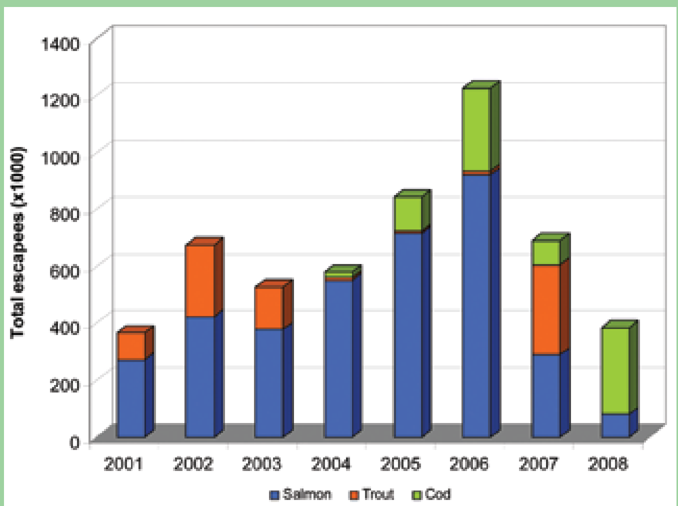

Figure 2. Number of reported escapes of cultured trout, salmon and Atlantic cod from Norwegian fish farms in the period 2001-2008 (Data: Norwegian Directorate of Fisheries, 2009).

nutritional studies to develop feeds for on-growing, disease control and vaccine development, and studies into methods for the control of precocious sexual maturation in cultured stocks. Pre-harvest sexual maturation is of major concern because it can affect growth, flesh quality and survival. In addition, the release of fertilized eggs and the escape of fish from sea cages were regarded as additional issues of concern. In light of the events experienced with Atlantic salmon farming, environmental worries focused on the potential detrimental effects of farmed escapees on vulnerable wild populations by direct competition for food, space and mates, spreading of diseases or 'contamination' of the gene pool following interbreeding. As a result, the emerging cod farming industry was put in the spotlight by environmental pressure groups, the media and popular press.

In comparison with the salmon industry, cod farming has given new challenges. First, many cod will mature before they have reached harvest size, and they may spawn in sea cages resulting in fertilized eggs being released into the surrounding area. Unfortunately, the photoperiod treatments that were effective in hindering precocious sexual maturation of Atlantic salmon have proven less successful with cod (Taranger et al., 2010). Second, cod are better than salmon at finding their way out of sea cages and cod may bite through the mesh of the cage nets to escape. Finally, cod are smaller than salmon when moved to sea cages making management operations more difficult and increasing the chances of accidental release.

An experiment performed near Austevoll to investigate the potential impact of farmed cod showed that 20-25% of cod larvae sampled in the vicinity of a farm could be traced to cod that had spawned in nearby sea cages (Jørstad et al., 2008). Elsewhere, researchers simulated escape incidents and monitored the dispersal of radio-tagged farmed cod. The results showed that escaped fish may disperse rapidly, and some were found on local spawning grounds (Uglem et al., 2008).

The goal is 'no escapes'

The proportions of reported escapes of farmed cod have been higher than those of salmon and trout (Fig. 2), and the Norwegian government has demanded an increased industry focus on preventive measures, control systems and technical requirements for aquaculture (NYTEK regulations). An Escape Commission for Aquaculture (RKA) has been appointed to examine the causes of farmed fish escapees, and to propose new standards and regulations. In line with this, the Directorate of Fisheries has established a "Vision zero escapes" programme setting out a number of measures aimed at reducing farmed fish escapes by applying stricter operational regimes. One positive result has been a reduction in escaped salmon in the most recent years (Fig. 2).

For farmed cod in particular, the government's ambition is to introduce requirements for achieving 'zero release' of eggs and gametes by 2015. It is expected that improved legislation and tailored technological solutions will help to reduce the number of cod escapes as already achieved for salmon. Improved technology will, however, not prevent farmed cod from spawning in sea cages nor can it prevent interbreeding of farm escapees with wild cod of local stocks in the event of fish escapes. The development of land-based facilities has been advocated as measure to hinder farmed cod escapes but this would require very large initial capital investment on the part of the farmers. In the current economic climate this is probably an unrealistic proposition.

Sterile cod: the way forward?

The production of sterile cod is an option for reproductive containment that would meet both industrial and environmental criteria. Sterile fish and shellfish can be produced by the induction of polyploidy, particularly triploidy. Triploid fish have three sets of chromosomes – two from the mother and one from the father. They are produced by application of thermal or pressure treatments shortly after egg fertilization. The treatment prevents the extrusion of the second polar body when cell division is resumed (Fig. 3). Pressure shocks are usually preferred over thermal treatments because they are more efficient and less damaging to

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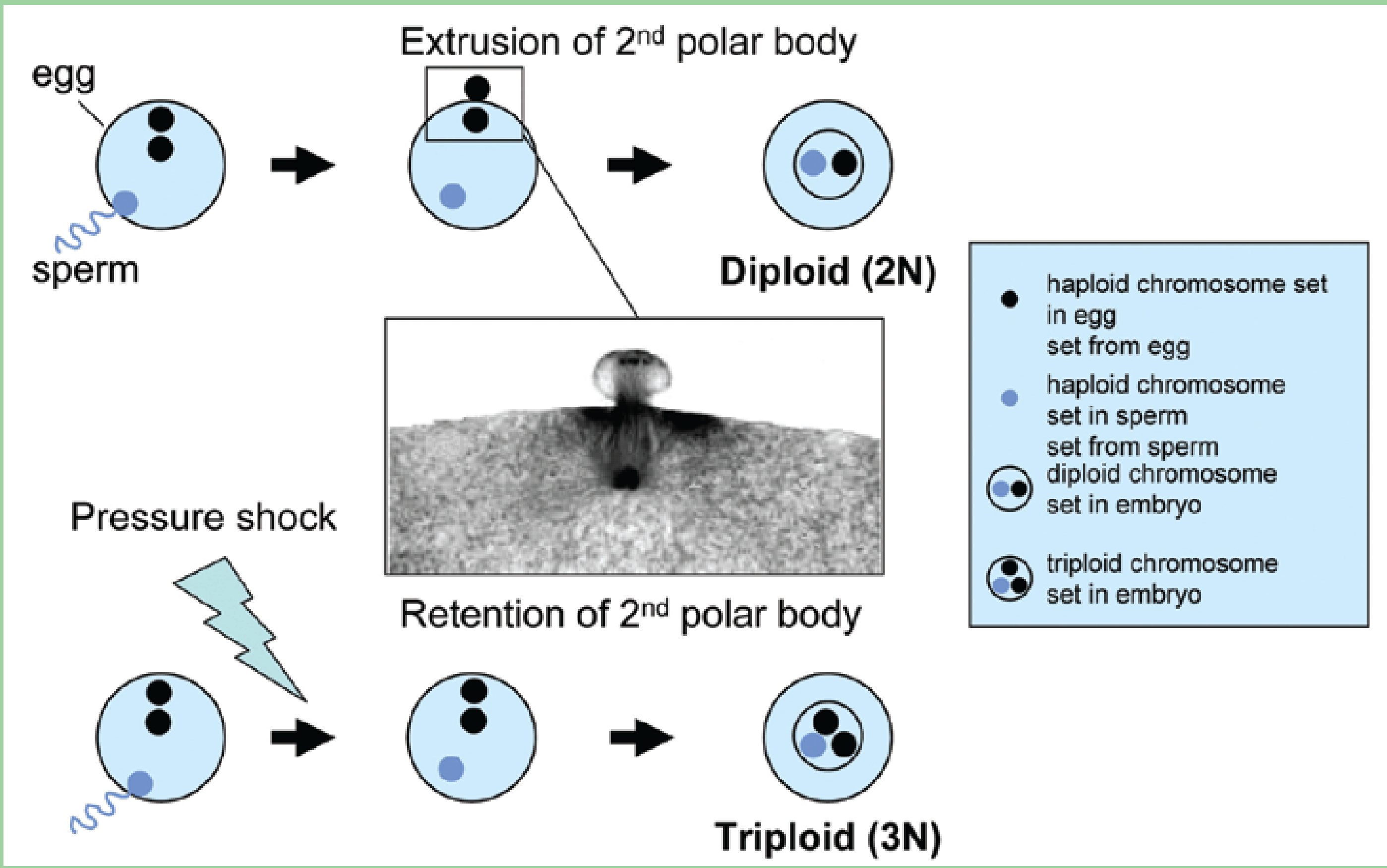

Figure 3. The process of triploidy induction in fish using high level pressure shocks.

the eggs than thermal shocks (heat or cold). One possible disadvantage with triploid induction using pressure shocks is that it requires purpose-built equipment that can produce pressures of 550-650 bars for treatment of the newly-fertilized eggs.

Due to the genetic condition of triploid fish (one extra set of chromosomes), the germ cells cannot undergo all the meiotic divisions needed to produce viable eggs or sperm, so the fish are usually functionally sterile. In the event of escape they cannot successfully reproduce in the wild. Triploids also have the potential to grow faster and perform better than diploids, and are not expected to suffer the flesh deterioration observed in normal diploid fish during the course of sexual maturation and reproductive development. Reduced growth and flesh deterioration occurs because normal diploid fish allocate a proportion of their growth capacity and energy reserves towards reproduction (Fig. 4). Although the production of sterile triploids is endorsed by several national and international agencies for management purposes (Piferrer et al., 2009), the performance of cultured triploids is variable and the theoretical growth and flesh quality advantages are not always seen in practice. As such, convincing the global fish farming industries to use triploids, rather than diploids, for production has not always been easy.

In Europe and USA, triploidy is currently applied in Pacific oyster (*Crassostrea gigas*) production as it provides a faster growing and more palatable product. Triploid rainbow trout are produced when large fish are in demand, such as for smoking. Sterile triploid rainbow trout and other salmonids are also raised for the reproductive containment of fish released by angling associations in several European countries. The introduction of exotic fish species, such as grass carp (*Ctenopharyngodon idella*) in USA for the purpose of weed control in ponds, requires that the fish are sterile triploids to reduce the threat of uncontrolled reproduction in the wild.

Triploid cod can be reared to market size, they show impaired gonad development (Fig. 4), and do not produce viable gametes. As such, the introduction of this technology could be a tool for minimizing the ecological risk of farmed cod escapees. Nevertheless, it remains to be demonstrated that the technique can be applied reliably for mass-producing 100% sterile fish with sufficient improvement in growth and survival to make them competitive on the market and attractive for the industry.

Triploid fish are not considered genetically modified organisms (GMOs) according to European regulations (EU, Directive 90/220/CEE), and they are not subject to the tight rules applying to the use and containment of GMOs in farming. Nevertheless, the perception of triploid fish by fish farmers, traders and consumers is rather blurred on this point and few efforts have been made to develop the technique for mass use. As such, further effort should be made to inform aquaculture industry operators and the general public about the advantages and disadvantages of triploidy technology and what it entails. Aside from the likelihood that some form of fish sterilization will be mandatory in the future, such an information campaign could potentially help tackling some unresolved issues regarding the perception and use of domesticated fish in aquaculture. Finally, if successful, it could make an important contribution towards the development of a more sustainable and environmentally-friendly cod farming industry.

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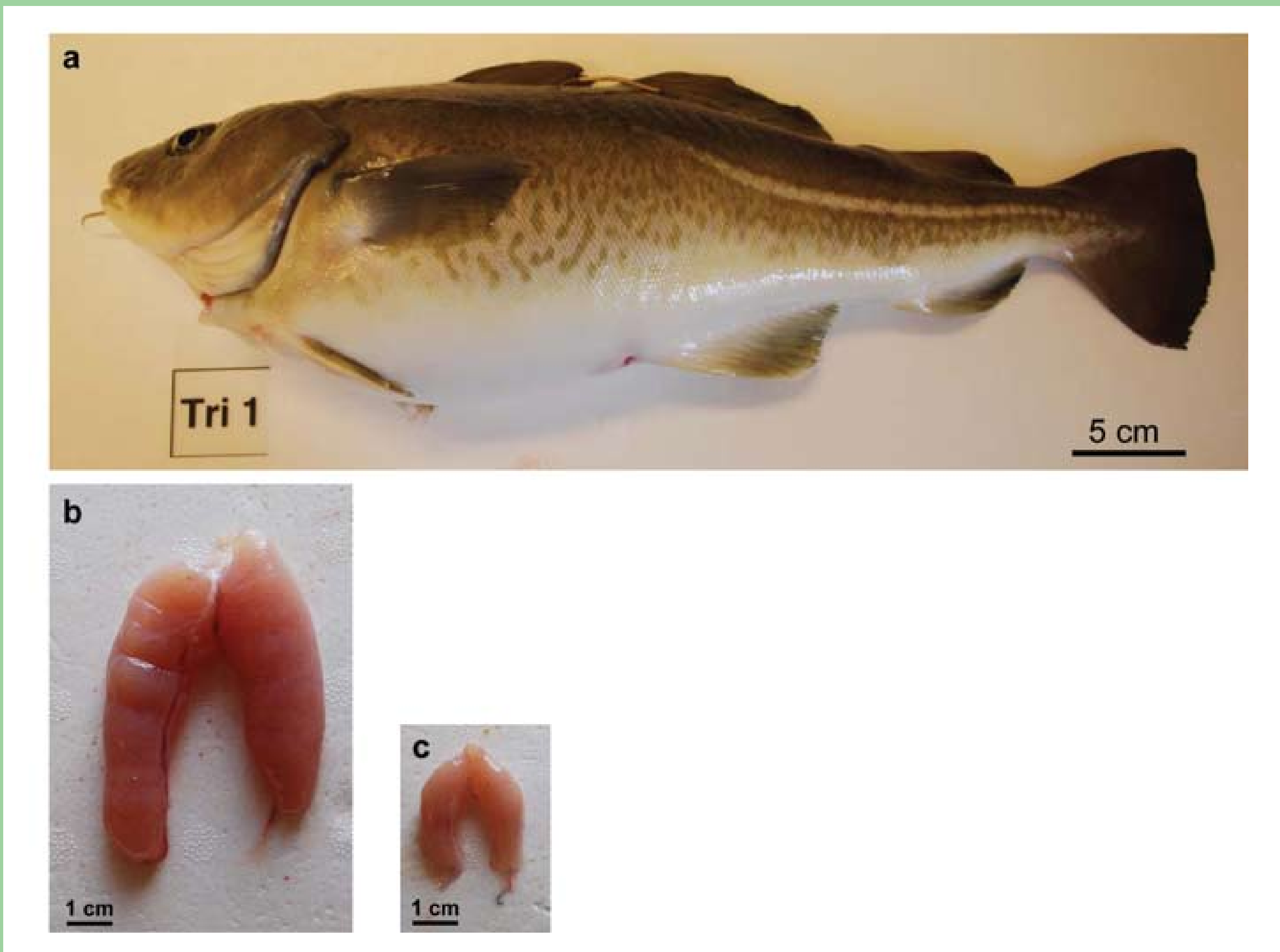

Figure 4. Picture of a 3-year-old triploid cod (a). Gonad develpment in diploid (b) and triploid (c) female fish of similar body size (ca. total length= 55 cm; body weight= 1800 g).