The prerequisites for, and potential of, cod farming in Sweden

Förutsättningar och potential för torskodling I Sverige

Jason Bailey*, Jana Pickova# & Anders Alanärä*

*Department of Aquaculture, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden.
#Department of Food Science, Swedish University of Agricultural Sciences, PO Box 7051, SE-750 07 Uppsala, Sweden.

Correspondence to: Anders Alanärä, E-mail: anders.alanara@vabr.slu.se

Sammanfattning

Bakgrund

Tillgången på torsk i våra världshav har minskat år från år. Den totala fångsten i världen ligger idag på ca 1/3 av fångsten 1970. Nedgången i fisket har resulterat i en stigande prisbild där torsk idag knappast längre kan ses som en billig ”vardagsfisk”. Kombinationen av ökande priser på torsk och sjunkande priser på lax och regnbåge har lett till att fiskodlingsindustrin världen runt nu satsar resurser på att utveckla torskodling.

Den Norska staten och odlingsindustrin satsar idag stora pengar på att utveckla torskodling. Idag finns ca 17 sättfiskanläggningar för torsk och hundratals odlingstillstånd för matfiskproduktion. Under 2003 producerades ca 3 miljoner yngel som förväntas ge en matfiskproduktion av 7500 ton 2004. För 2005 är prognosen beräknad till 20 000 ton torsk.

I Danmark satsar man främst på landbaserad odling av torsk, bl a via ett projekt där målet är att producera 100 ton i ett recirkulerande system.

På Island producerades ca 250 000 torskyngel under 2003 som under det kommande året odlas till 3-4 kg storlek i kassar. Dessutom insamlades ca 500 000 vilda yngel (2-3 g) från havet för vidare odling i kassar.

Produktionen av torsk i Storbritannien var ca 90 ton år 2003, men beräknas nå ca 3-4 000 ton under de närmaste fyra åren.

I Kanada satsar staten och privata intressenter årligen stora pengar på att utveckla torskodling. Längs kusten vid Newfoundland finns idag 49 företag som tillsammans odlar ca 200 ton torsk. Produktionen beräknas öka snabbt och uppskattas bara för Newfoundland uppgå till 15-30 000 ton år 2010.

Som beskrivs i texten ovan så är tilltron på torsk som en ny art för vattenbruk hög runt om i världen. Sverige är ett land med stor tradition att fiska och äta torsk, samt har riklig tillgång på kustområden som skulle kunna vara lämplig för odling. En del intressenter har undersökt möjligheten för torskodling i Sverige, men arbetet har ej tagit fart på samma sätt som i andra länder.

Syftet med denna rapport är att beskriva de biologiska, tekniska och ekonomiska förutsättningarna för torskodling generellt och för Sverige specifikt.

Odlingsteknik och –biologi

Rom- och yngelstadiet: Beroende på ursprung så leker torsken mellan januari till april. Honan kan producera ca 250 ägg per g kroppsvikt, vilket för en 5 kg fisk blir ca 1.2 miljoner romkorn. Vid en temperatur av 6-9°C tar det ca 10 dagar för rommen att kläcka. Under de första 6-8 dygnen lever ynglet enbart på gulesäcken, men när den är förbrukad måste ynglet börja äta små kräftdjur. För att kunna odla torsk på ett effektivt sätt måste ynglen efter en tid tillvänjas torrfoder. Denna process startar ca 35-40 dagar efter kläckningen. Tillvänjningen går till så att torrfoder under en period ges tillsammans med levande föda för att successivt övergå till enbart artificiell föda efter ca 20 dagar. Hela denna process, från att utfodra med levande kräftdjur till att invänja och övergå till torrfoder, är den mest kritiska och arbetsintensiva perioden vid odling av torsk. Förutsatt att allt fungerar och inga sjukdomar bryter ut så kan odlaren förvänta sig en överlevnad på 5-25% under denna period. En fortsatt utveckling av odlingsteknik, rutiner och odlingsmaterial kommer sannolikt att förbättra överlevnaden på sikt.

Sättfiskodling: Torsken kan inte flyttas till kassar i havet förrän de nått en ålder av 6-7 månader. Vid denna ålder väger de mellan 25-50 g. Beroende på tidpunkten för kläckning sker transporten från sättfiskodlingen till kassodlingen vanligen under hösten i Norge. I Sverige med något annorlunda klimatsituation kan sen höst vara olämpligt för utsättning. Ett tänkbart scenario är därför att torsken hålls i sättfiskodling under ca ett år och flyttas till kassodling under våren. Denna senareläggning leder till att torsken sannolikt är 75-100 g vid utsättningen. I framtiden kommer dock sättfisk av torsk att kunna produceras vid olika tider på året, genom styrning av tiden för könsmognad hos föräldrafisken. Under sättfiskstadiet är det vanligt med kannibalism. Det är därför nödvändigt att sortera fisken regelbundet och att ge tillräckligt med mat för att undvika detta problem. I övrigt liknar denna fas i odlingscykeln den för lax och regnbåge varför inga specifika ”torskproblem” kan identifieras. Innan utsättning i kassar vaccineras torsken mot de vanligaste sjukdomarna som kan förekomma.

Matfiskodling: Teknik och rutiner för matfiskodling av torsk är i princip de samma som de för laxfisk. Tätheten av fisk är en viktig fråga för intensiv matfiskproduktion. Erfarenheterna är ännu så länge få för torsk men preliminära data indikerar en täthet om 40 kg per m^3. Utfodring av fisk i odling är av stor betydelse därför att fodret vanligen står för 50-60% av produktionskostnaden. Laxfisk utfodras vanligen i två intensiva måltider per dygn, morgon och kväll. Det mesta tyder på att liknande utfodringsstrategier passar för torsk. Ett problem som uppdagats vid intensiv utfodring av torsk är att de kan utveckla extremt stor lever, vilket kan leda till ett allvarligt sjukdomstillstånd och ökad dödlighet. Problemet är sannolikt kopplat till foder med för högt fettinnehåll. Torsk bör ej utfodras med foder innehållande mer än 12-17% fett, vilket kan jämföras med dagens foder för laxfisk som vanligen innehåller över 20% fett. Två huvudsakliga odlingssystem kan identifieras; nätkassar och landbaserade bassänger. Fördelen med kassodling är att investerings- och driftskostnader är relativt låga, medan nackdelar är arbetsmiljön och risken för haveri. Landbaserad odling ger förutsättningar för en bra arbetsmiljö, men de kanske viktigaste fördelarna är möjligheten att optimera produktionen, förhindra att fisk rymmer, samt möjligheten att rena utgående odlingsvatten. Det stora frågetecknet är dock huruvida de är tillräckligt kostnadseffektiva eftersom investerings- och driftskostnader är höga.

Tillväxteffektivitet

En övergripande bild av tillväxtkapaciteten för torsk i odling ger ett tämligen splittrad intryck. Olika studier visar på en mycket varierande tillväxt, d v s alltifrån extrem dålig till mycket god. Detta är dock inte förvånande för en ny art i odling. Naturlig variation i anpassning till olika miljöer mellan olika stammar ger ofta skiftande resultat när den nya arten tas in i odling. Forskning och praktisk erfarenhet från Norge indikerar dock att torskens tillväxtkapaciteten är mycket god. Teoretiska simuleringar visar att tillväxten ligger mycket nära den för t ex lax och regnbåge. Detta trots att torsk ännu så länge ej utvecklat tillväxtkapaciteten via avelsprogram. Sannolikt har torsken längs den svenska kusten en liknande tillväxtpotential som den i Norge. Ett annat sätt att utvärdera tillväxteffektivitet är att mäta mängden energi som åtgår för att producera ett kg tillväxt. Även här ligger torsk mycket bra till i jämförelse med mer etablerade arter. Torsk ser redan idag ut att vara lika effektiv som lax och regnbåge på att omvandla energin i födan till kroppstillväxt. Ett avelsprogram anses ofta som en grundförutsättning för att kommersiellt utveckla en ny art i odling. Erfarenheter från avelsprogrammen på laxfiskar är att tillväxtegenskaperna ökar med 10-15% per generation. Det finns således mer att utveckla inom torskodling även om förutsättningarna redan idag ser bra ut.

Produktionskostnad

Kostnaden för att producera torsk simulerades för sex olika kustområden i Sverige; Umeå, Sundsvall, Stockholms skärgård, Karlskrona, Båstad, samt Lysekil. För samtliga områden samlades data in för ytvattentemperaturer. Resultatet från simuleringen visar att de bästa naturliga förutsättningarna för torskodling, med avseende på vattentemperatur, återfinns i Karlskronaregionen. En torsk som sätt ut i kassar vid en vikt av 100 g växer teoretiskt till 3.6 kg på 18 månader i denna region. Produktionskostnaden för en 500 tons torskodling i Karlskronaområdet beräknas till ca 21 kr per kg. Norrlandskusten erbjuder hyggliga förutsättningar, men den långa och kalla vintern ger begränsningar i produktionen. Den svenska västkusten har generellt goda villkor för torskodling, dock med ett visst frågetecken rörande höga sommartemperaturer med risk för reducerad tillväxt och förhöjd dödlighet. Problem med höga ytvattentemperaturer kan dock motverkas tekniskt genom att odla fisken i djupa kassar (20-30 m djupa) eller genom att pumpa upp kallare djupvatten in i odlingen.

Landbaserad odling har högre investerings- och driftskostnader, samtidigt som odlingen kan ske mer intensivt med bättre utnyttjande av anläggningen. Beräkningarna gjorda här visar på en produktionskostnad om ca 32 kr per kg i landbaserad odling. På grund av begränsad kunskap och erfarenhet av odling i landbaserade system är det svårt att simulera en optimal produktion av torsk, vilket gör att kostnaden sannolikt är överskattad.

Med bättre teknik, kunskap och produktionsegenskaper via avel kommer kostnaden i framtiden att kunna bli lägre. Produktionskostnaden för t ex lax i Norge var under pionjärtiden i början av 1980-talet ca 60 kr per kg, medan kostnaden idag ligger på 16-17 kr per kg producerad fisk. För torskodling kan man konstatera att den initiala kostnaden kommer att vara mycket lägre, samtidigt som det mesta pekar på att torsk i framtiden kommer att kosta ungefär lika mycket som lax och regnbåge att producera.

Miljöbedömning och lokaliseringsfrågor

Fiskodling kan förorsaka förändringar i miljön på flera olika sätt, antingen på kort sikt via lukt, ljud och påverkan på landskapsbilden eller på lång sikt via fysiska och biologiska förändringar. De huvudsakliga miljöeffekterna av fiskodling är:

- Utsläpp av organsikt material och näringsämnen
- Genetiska och ekologiska interaktioner med vild fisk
- Risk för spridning av sjukdomar från odlad till vild fisk

Utsläppen av organiskt material och näringsämnen till våra hav anses idag vara alltför omfattande. Miljösituationen i egentliga Östersjön och Västerhavet är ansträngd, med närsaltstillskott som överskriden den kritiska belastningen. Problem med övergödning finns nästan uteslutande i egentliga Östersjön och Västerhavet, medan inga eller små tecken på övergödning kan ses i Bottenviken och Bottenhavet.

Regeringen har antagit 15 miljökvalitetsmål som ska visa vägen till ett ekologiskt hållbart samhälle inom en generation. Ett av dessa delmål – *Ingen övergödning* - behandlar miljösituationen i sjöar och vattendrag, samt kust och hav. Som huvudmål för övergödningssituationen i kust och hav har regeringen lagt fast följande: näringsförhållandena skall motsvara i stort det tillstånd som rådde under 1940-talet och att tillförseln av näringsämnen till havet inte orsakar någon övergödning. Denna målsättning får givetvis återverkningar på nya verksamheter som vill nyttja havet till produktion. Konflikten mellan miljömål och nya aktiviteter som fiskodling är till stor del en fråga om skala. På den stora nationella skalan så har Sverige ambitionen att minska miljöbelastningen på haven, medan människor på lokal nivå söker efter olika sätt att skapa sysselsättning. Dessa skilda intressen är mycket svåra för t ex länsstyrelsen att hantera och när ”försiktighetsprincipen” tillämpas så faller de flesta ansökningar om odlingstillstånd på bekostnad för nationella miljömål. En kärnfråga är såldes om vi både kan agera för att skapa utrymme för t ex fiskodling längs kusten och samtidigt verka för att miljömål uppnås.

Vilka konsekvenser får rådande miljösituation i havet och beslutade miljömål för fiskodling generellt och torskodling specifikt? Tänkbara scenarios är följande:

1. Det kommer att bli mycket svårt att få igenom tillståndsansökningar för fiskodling i egentliga Östersjön och Västerhavet. Speciellt gäller detta tillstånd med en årsproduktion större än 100 ton.
2. Fiskodling i Östersjön och Västerhavet kan sannolikt endast medges av politiska skäl där miljöfrågorna underställes andra viktiga frågor. T ex regionalpolitik (sysselsättning i glesbygd) eller nationella bevarandeåtgärder för att rädda den vilda torsken.
3. Fiskodling kan med dagens kunskap och metoder lokaliseras till sådana områden där den lokala miljöpåverkan blir mycket liten.
4. Miljösituationen i Bottenhavet är tämligen god och bör kunna medge odlingstillstånd.
5. Landbaserade odlingar har fördelen att partikulärt material kan filtreras bort och avlägsnas utsläppet. Detta reducerar drastiskt miljöbelastningen av fosfor och organiskt (syretärande) material. I vattnet lösta kväveprodukter kan idag renas med hygglig effektivitet, men osäkerhet råder om metoderna är tillräckligt kostnadseffektiva.
6. Odling i slutna kassar (gummiduk istället för nät) med uppsamling och rening av partikulärt material är en ny och lovande odlingsteknik, men i likhet med punkt 5 så finns frågetecken för kväveutsläppen.

Odlad fisk är efter ett antal generationer i odling och speciellt via avel ***genetiskt*** annorlunda än deras vilda anfäder. Om odlad fisk rymmer och lyckas ta sig till reproduktionsområden så kan de leka med vild fisk och därmed vara ett hot mot biologisk mångfald. Odlad torsk utgör sannolikt ett något större hot mot vilda bestånd jämfört med t ex lax av två skäl: (1) avståndet till potentiella lekområden kan vara kort och (2) torsk kan leka i odlingen varefter rommen sprids till omgivande vatten. Hur kan genetiska risker med torskodling reduceras eller undvikas? De huvudsakliga åtgärderna som föreslås är:

- Använd kassar utvecklade för ”off-shore” odling. Reducerar risken för haverier.
- Odla torsk i landbaserade odlingar där risken för rymlingar mer eller mindre kan elimineras.
- Tidpunkten för slakt bör ske i god tid före det att torsken blir lekmogen – undvika lek i kassarna. Ingen könsmogen fisk i nätkassar.
- Använda och utveckla tekniker för att skapa steril fisk.

Ett stort antal fisk som rymmer från en odling kan leda till höga tätheter i den vilda fiskens miljö och därmed påverka tillväxt och dödlighet – ***ekologisk konkurrens***. Ekologiska risker till följd av konkurrens bedöms som relativt små för torsk, speciellt så länge de vilda populationerna befinner sig långt under sin normala status.

Sjukdomar finns normalt i de vilda fiskarnas miljö. Problemet med fiskodling och sjukdomar är dock inte i första hand de som redan finns i området för odling, utan de som kan komma till området med den odlade fisken. Sverige har idag en gynnsam situation med få allvarliga sjukdomsproblem. Sjukdomar som idag ej finns i Sverige förekommer dock i andra länder med fiskodling, varför det finns en risk att dessa ”följer med” t ex torsk som importeras. Torsk är i princip mottaglig för de vanligaste sjukdomarna som idag förekommer inom laxfiskodling (se bilaga 1 för mer information om torsk och sjukdomar). Det är ej heller några skillnader mot andra fiskarter i hur de sprids mellan odlad och vild torsk. Torsk bör ej odlas i samma anläggning som t ex regnbåge. För att reducera riskerna med sjukdomsspridning bör samma regler gälla som idag tillämpas för andra arter, t ex regnbåge.

Contents

Introduction

Stocks of Atlantic cod (*Gadus morhua*) are in a steady state of decline, and have been so since the late seventies (Figure 1, FAO, 2003). This has been especially apparent in the Northwest Atlantic where a crash in the stocks off the east coast of Canada resulted in a complete ban on fishing in 1992. Whereas the stocks closer to Europe have declined but are still open for fishery. The North Sea and the Kattegat cod populations are severally threatened and the fishery there has to be stopped. Some of the smaller coastal cod stocks in the Skagerrak seem now to be eradicated (Svedäng et al., 2002).

Decreasing biomass of wild fish has led to increasing prices and has placed cod in the unfamiliar position of luxury fish. No longer can it be considered a cheap source of white-fleshed fish protein. Increased prices of cod, in conjunction with decreased prices of salmon, has attracted the attention of the fish-farming industry. Newfoundland, Iceland, Scotland, and Norway have released research programmes aimed at enhancing and developing the cod farming industry. Norway in particular has stated that Norwegian farmed cod will approach 400 000 tonnes by the year 2010.

The aim of this report is to examine some of the possibilities, both economically and biologically, for the production of cod in Sweden. The report will aim to tackle the techniques and problems associated with the biological production of cod and the economic profitability of cod farming.

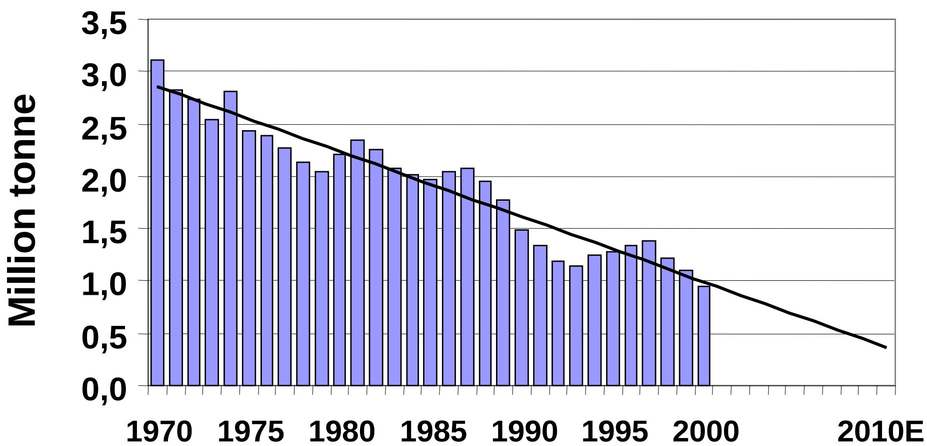

Figure 1. World wide catches of Cod between 1970 and 2000. Statistics from FAO (2003)

The Production of Atlantic Cod

While it is being promoted as a new industry, cod farming has been going on for more than 100 years in Newfoundland, USA and Norway. However, up until the 1970s this industry was in the form of enhancement. Larvae were produced in hatcheries and released directly into the sea. This enhancement has likely had little impact on the wild population of cod but it has helped build a foundation for the culture of marine species in captivity.

In the 1970s and 1980s, interest grew in the use of cod for fish-farming and in 1977 cod were raised for the first time from egg to adult in captivity (Walden, 2000). In Newfoundland and Norway intensive farming began to take shape in the mid-1980s through the use of juveniles raised in controlled enclosures (Kvenseth & Öiestad, 1984). Due to the high rate of mortality associated with rearing cod from eggs in captivity, juvenile fish were being caught, transferred to grow-out cages and fed to a larger size for market. This business proved to be lucrative and has given us further information about the production of cod in sea cages. This type of cod farming is practised today in Norway and Iceland (Nordic cod project report 2003).

A good source of juvenile fish has always been and remains to be one of the major obstacles in the development of the cod farming industry. Development in Sweden then, must first begin with the establishment of a reliable supply of high quality juveniles. Such activities have been started in 1993 at the Institute of Marine Research (Pickova & Larsson, 2003) and in 2003 by private investors, but lack of interest from the central or regional partners or the administration has stopped the projects. Last year fingerlings were produced in a hatchery on the Swedish west coast in a first season test.

Life-Cycle

Gadus morhua can be found in the North Atlantic, the Baltic and the Barents Seas. It is a very adaptable species with different stocks in a variety of areas. The lifespan of the cod may be greater than 30 years and growth may exceed 50 kg (Walden, 2000).

Cod become mature at 2-7 years of age depending on the stock and rate of growth (Godø & Moksness, 1987; Karlsen *et al.*, 1995; Walden, 2000; Hansen *et al.*, 2001). Mature females release 10-20 batches of eggs at intervals of 60-75 hours with each batch containing up to several hundred thousand eggs (Olsen, 1997; Walden, 2000). Spawning occurs at different times for different stocks, but usually occurs in the spring between January and April (Hansen *et al.*, 2001). Females can produce about 250 eggs per gram of body weight and so total fecundity for each female may be several million very small eggs (1-2 mm diameter, 0.1 g fresh weight) (Olsen, 1997; Walden, 2000).

At 6 - 9ºC the eggs hatch in around 10 days depending on the stock of the parental cod (van der Meeren 1993, Olsen, 1997; Walden 2000). Newly hatched cod fry measure 3.5 – 5.0 mm in length (Moksness & Støle, 1997; Walden, 2000; Hunt von Herbing, 2001). For the first 6 – 8 days, again depending on temperature and the stock of cod, fry feed off their yolk sacs (Olsen, 1997; Walden 2000; Hunt von Herbing, 2001). As the yolk sac is depleted, the fry begin to feed on zooplankton. This is a critical period for the developing cod and is one of the most crucial times for the hatchery manager in order to prevent abnormally high rates of mortality (Baskerville-Bidges & Kling, 2000a; Baskerville-Bidges & Kling, 2000b).

The two Baltic cod stocks are well adapted to the brackish water environment, with implications on their life cycle. Obvious peculiarities are e.g. a prolonged and late spawning season (April – November, with a peak in July - August) and a neutral egg buoyancy at 12-17‰ (eastern stock, Nissling and Westin, 1997) compared to ca 30‰ for oceanic stocks. Experiments were performed with Baltic cod in Lysekil 1990-93 to adapt adult and mature Baltic cod to the higher salinity at the west coast, and to test the effect of different salinity in the larval and fingerling culture (Pickova and Larsson, 199?). Adult fish survived an direct transfer from 7 to 27‰, spawned and grew well after that. Eggs had the same (poor) hatching rate and larvae and fry had the same growth and survival rate in all salinities tested. It was therefore concluded that salinity is not a limiting factor for the farming of Baltic cod. The findings of Thorsen et al (1996) are in line with this assumption, since the lower buoyancy is defined in the female and not during the swelling of the egg after they once have been released from the gonad. The low buoyancy has most likely been developed during the whole period of the formation of Baltic Sea and its brackish history (Bagge 1981).

Current knowledge of cod culture

Cod larvae production

As stated, the most problematic area for the development of commercial cod-farming has been the ability to obtain a reliable supply of high quality juveniles. As has been the trend for the salmon farming industry, the rearing and selling of juvenile cod will be a separate business venture from that of growing the fish to market size. This partitioning will become even more important for the cod industry since the raising of juveniles is more difficult for cod than it is for salmon. Cod need to be fed with zooplankton during the early stages of development and this requires that plankton is cultured. In addition, cod larvae require different weaning processes to dry feed.

Broodstock Management

Broodstock cod have traditionally come from a wild population found in the vicinity of the hatchery. However, with evidence suggesting different rates of growth and maturation for different cod stocks (Brander, 1994; Svåsand *et al.*, 1996; Purchase & Brown, 2001), one might expect that this will change. Like all other farming practices, selection will take place for faster growing and later maturing cod.

Differentiation among cod populations was reported by Møller (1966, 1968) and genetic differences were later demonstrated by Dahle and Jørstad (1993) and Dahle (1994). Svåsand *et al.* (1996) have reported differences in growth, hepatosomatic, and gonadosomatic indexes between Arcto-Norwegian (also known as the Northeast Arctic cod, a large stock of cod, *Gadus morhua* L.) and Norwegian coastal cod stock, and Purchase and Brown (2001) have suggested that genetic differences exist between 4 stocks of cod on the East coast of North America. The Faroe Banks cod stock grows faster than the Faroe Plateau stock. Swedish cod stocks, such as the Baltic eastern and western stocks and the North Sea cod and the different coastal cod stocks have also been shown to be distinctly separated (Sick, 1965; Jamieson & Otterlind, 1971; Larsson, P-O., Institute of Marine Research, Lysekil, pers. comm.). These differences point to a differentiation in cod stocks and indicate that selection may be possible and beneficial for cod farming.

Broodstock fish are usually held in onshore tanks and stocked at densities of about 5 - 10 kg $\cdot$ m^{-3} using a 3:1 or a 3:2 female:male ratio (Olsen, 1997; Walden, 2000). Because it is very important that broodstock fish produce high numbers of good quality eggs, they are fed using a high quality feed. In doing so, good quality eggs and sperm will be obtained, and therefore increase the likelihood of good survival in the fry (Rosenlund, 1998; 2002).

Once it is known that spawning time is approaching, tank overflows are fitted with mesh bags with a very small (<1mm) mesh (Olsen, 1997; Walden, 2000). Cod will spawn freely in the tanks and because the eggs float to the surface, they are collected in mesh bags as they drift out into the overflow (Figure 2)(Olsen, 1997; Walden, 2000; Hansen *et al.,* 2001). Mesh bags are checked periodically, depending on the number of spawning adults and eggs produced, and replaced as required.

Figure 2. Egg collection utilising an external collection tank. The bag is connected to the outflow pipe of the broodstock tank (Photo courtesy of The Ocean Sciences Centre, Newfoundland).

A commercially successful cod-farming industry, which is able to produce a year-round supply of cod, will ultimately be dependent on a year-round supply of juveniles. Researchers have been successful in producing gametes outside the natural season through the manipulation of photoperiod length (Olsen, 1997; Hansen *et al.,* 2001; Hemre *et al.*, 2002).

Hatching & Early Rearing

Once the eggs have been collected from the broodstock tanks, they are disinfected and placed in small incubation tanks (Figure 3). These are normally about 70 L cylindrical tanks with conical bottoms. During incubation, eggs are held in darkness and flow rates are kept low (0.3 – 2.0 L $\cdot$ min^{-1}). The inflow water is filtered to 5 microns and sterilised using UV light or ozone. Temperature is maintained at 6 – 8ºC at which temperature the cod will hatch in 10– 14 days (Olsen, 1997; Walden, 2000).

Figure 3. Conical egg incubation tanks at the Ocean Sciences Centre, St. John's, Newfoundland.

Eggs can be randomly selected from the population and examined for symmetry in the first cleavage stages under a microscope (Pickova *et al*. 1997). The day before hatching is expected in more than 50% of the population, the eggs are disinfected once again and transferred to larval tanks (Olsen, 1997; Walden, 2000). These slightly larger tanks are between 100 – 7000 L and will be the home of the larval cod during first-feeding.

In the new tanks, cod are stocked at densities of between 50 – 100 larvae $\cdot L^{-1}$ (Olsen, 1997; Walden, 2000). Over the first few days, the temperature of the water is increased from 6 – 8°C to about 10 - 11°C (Pickova & Larsson 1992, Van der Meeren 1993). The inflow of the water should be kept under the surface in order to minimise disturbance and the rate should be kept at about 0.3 – 1.0 L $\cdot min^{-1}$ depending on the size of the holding units (Olsen, 1997; Baskerville-Bridges & Kling, 2000; Walden, 2000). As the larvae grow these flow rates can be increased slightly.

A hatchery also has to keep live feed for cod larvae in culture. The addition of live feed into the tanks also adds to the load on the systems and makes good flow rates and constant monitoring necessary. In addition, light regimens at which the larvae and adult cod are raised have to be investigated for each stock used since the literature can sometimes show contradicting results.

Figure 4. The production of algae for larval "green water". Background lights illuminate the algal tanks (Photo courtesy of The Ocean Sciences Centre, Newfoundland).

Algae grown in intensive culture or obtained as ready to use products are added to the larval tanks immediately following hatching. This water, known as green water, will provide food for the planktonic animals upon which the larval cod will feed (Figure 4). Rotifers (*Brachionus plicatilis*) enriched with commercial enrichment media containing n3 fatty acids (n3 HUFA, Highly unsaturated fatty acids) and possibly brine shrimp (*Artemia sp.* nauplii) enriched with docosahexanoic fatty acid (DHA) will make up the feed for the larvae during the first 50 days until feeding on inert, pelleted feed is well established (figures 5 & 6). Figure 6 illustrates the timing of feeding for a typical hatchery. The new technology which is tested in several commercial hatcheries today excludes the use of Artemia and feeding of rotifers together with the larval dry feed becomes more common. This development will continue and the goal is to be able to exclude all live feed handling. In general, rotifer culture has to be maintained in large volumes long before the time the larvae hatch. Even though the larvae have not yet begun to feed and obtain all their nutrients from the yolk sacs, it is essential that the rotifers are present from day 2. As the yolk sac starts to be utilized, the larvae begin to feed

Cod larvae must be weaned on each new type of feed offered and this means that the new feed is slowly offered in addition to the feed used at the different stages. There is always a large overlap of about a week where both types of feed are offered. *Artemia*, which are larger than the rotifers, are presented to the cod larvae at about 20 – 25 dph. However, rotifers are still added to the water for the next 5 – 7 days until it is determined that the larvae have begun feeding on Artemia (Howell 1984). When dry feed is fed together with rotifers, the period of both feed types has been even longer, up to 3 weeks-1 month.

Weaning onto commercial pellets usually occurs at about 35 – 40 dph and while Artemia are still being added. Provided this transfer is also successful and disease has not been a problem, the hatchery manager may expect survival rates of between 5 – 25% (Olsen, 1997; Walden, 2000). However, better survival rates have been shown in some hatcheries and it is likely that these numbers will increase slightly.

Figure 5. Rotifer production tanks. Rotifers are grown in brackish water and are fed a daily diet of baker's yeast, Culture Selco ®, and algae (*T-Isochrysis, Nannochloropsis* sp.). The water passes through a series of filtration systems including sand filters (20 µm) and cartridge filters (10 µm, 5 µm, 0.35 µm), and is irradiated using ultraviolet light (120,000 mw/sec) before reaching the rotifer culture tanks.

Figure 6. Artemia production tanks. A "decapsulation cone" can be seen at the far right. Dehydrated cysts, purchased from a supplier, have to be decapsulated before the hatching process can begin. Artemia grow and receive enrichment in these tanks before being transferred to the larval tanks. (Photo courtesy of The Ocean Sciences Centre, Newfoundland).

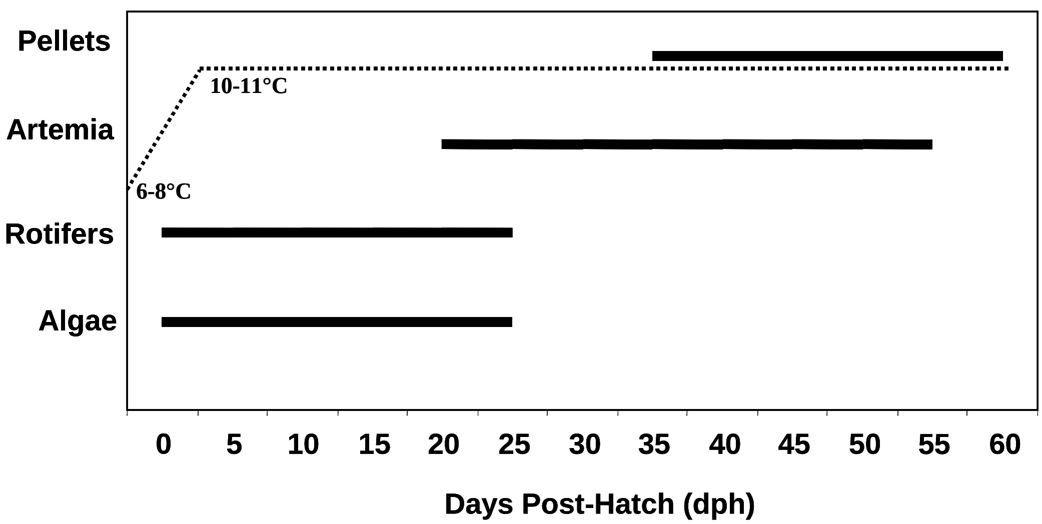

Figure 6. Approximate timing of feeding for hatchery-reared cod. Thick horizontal lines represent when each feed type is provided. Overlap allows for adjustment to the new feed. The hatched line shows how temperature is slowly increased over several days from 6-8ºC to 10-11ºC (see text for details).

The Nursery Stage

Juvenile cod can be moved into sea cages when they are about 6 – 7 months old. At this age they weigh between 25 – 50 g (Olsen, 1997; Walden, 2000; see also Björnsson & Steinarsson, 2002) and have attained this size entirely in the hatchery.

Figure 7. Size-grading of juvenile cod using a floating grader. (Photo courtesy of The Ocean Sciences Centre, Newfoundland).

Some hatcheries have observed a high rate of cannibalism in cod at this stage. Various techniques have attempted to tackle this problem but the best solution may be regular grading for size (starting with a 3 mm grid) and the provision of adequate amounts of feed (Figure 7). The colour of tanks and the water stream in the tank is of large importance for the rate of cannibalism. In some facilities no predation is observed (Troms Marin, Norway, pers. Comm.).

Once the cod have reached 25 – 50 g they are ready to be transferred to larger grow-out units. These may be sea cages similar to those used in the salmon industry, or large, land-based tanks. Here the cod will be grown to a market size of about 2 – 5 kg using essentially the same equipment and techniques familiar to the salmon farming industry. Figure 8 outlines the hatchery and nursery stages for cod rearing.

On-Growing

The farming of cod can have two possible goals. Cod may be farmed for the purpose of enhancement of failing wild stocks or for human consumption, again alleviating pressure on wild fish. Brief mention will be made of each type in order to give a more complete picture. However, the husbandry techniques used are essentially the same.

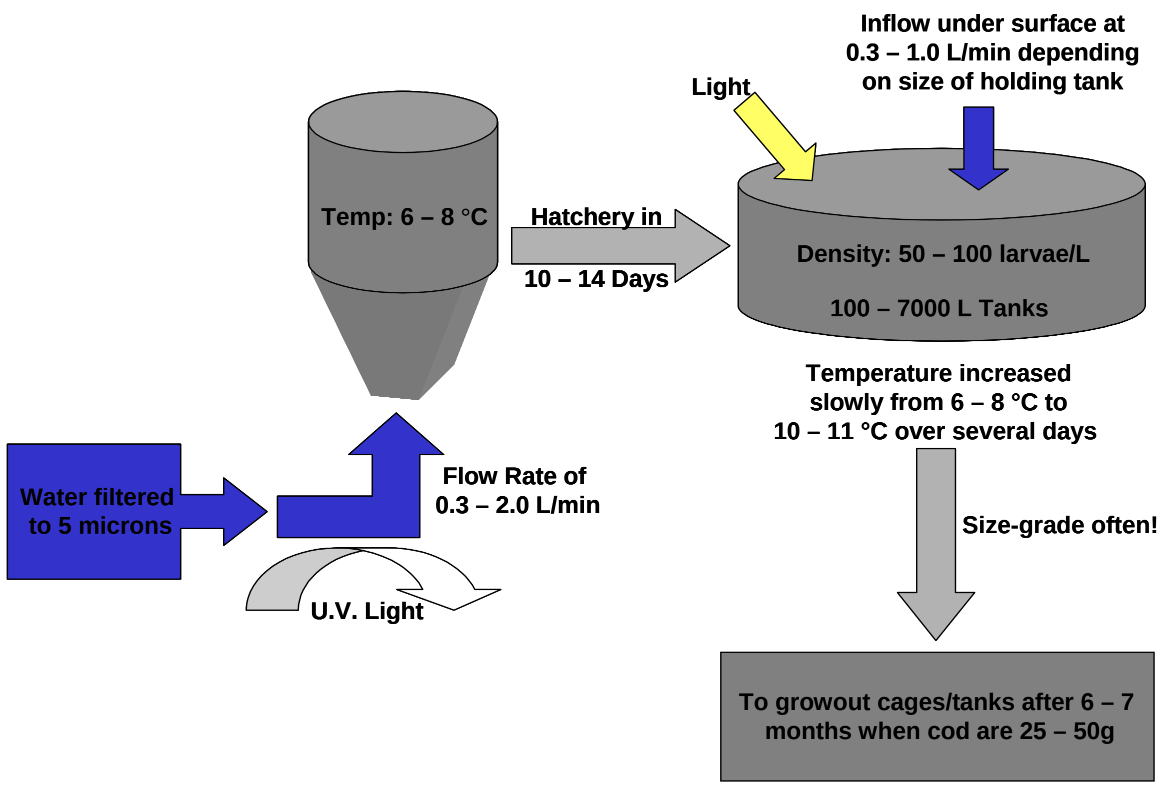

Figure 8. Schematic representation of the hatchery and nursery stages of rearing cod. Eggs are initially kept in 70L up-welling tanks with conical bottoms and 6-8ºC water filtered and treated with UV light. After 10-14 days hatched larvae are transferred to larger tanks and the temperature is slowly increased to 10-11ºC. Fish remain in these tanks for 6-7 months until reaching a size of 25-50g, size-grading often.

Sea Cages

As mentioned, the equipment and infrastructure for the on-growing of cod in sea cages is essentially the same as that used in the salmon farming industry (Figure 9 & 10). In addition to the equipment used, husbandry practices for cod farming are very similar to that of salmon farming. Cod are stocked such that the final stocking density at the next grading period is around 40 kg $\cdot m^3$ (Lambert & Dutil, 2001). Little is known about the feeding techniques required to optimise growth. However, practices similar to those used in the farming of salmonids (*e.g.* feeding morning and evening to satiation) have been used. Feeding once a day is also used in many cod farms.

Figure 9. Cage farming of Atlantic cod on the South coast of Newfoundland. (Photo courtesy of J. Moir and Andy Walsh).

During the early days of cod farming, wet feed was commonly used in the form of whole or chopped herring (*Clupea harengus*) or capelin (*Mallotus villosus*). More recently cod have been fed using salmonid diets in the form of dry pellets. Cod, however, have a tendency to develop extremely large livers, with weights of up to 10 - 15% of their total body weights (Rosenlund, 1998; 2002; Walden, 2000). This is not uncommon if fed a diet with too high lipid content. Most of the major companies now have some form of "cod diet" in their product line with the major difference being a lower fat and higher protein level compared to their salmon diet counterparts. Cod diets typically contain around 12-17% lipid, similar to, for example, turbot feed. New types of diet with a complete protein content based on plant sources have been developed. To make up for the energy decrease in the feed associated with the reduction in lipid content, extra protein is added (up to 50 – 60% of the total diet), thereby increasing the cost of a cod-formulated diet. However, cod have a limited ability to utilise protein for muscle production. This ability appears to be at about 50% protein (Rosenlund, 2002), after which protein is used for energy production. The conversion of protein to glucose precursors might lead to increased food conversion ratios and so higher levels of protein might not necessarily be better from the farmer's viewpoint.

Figure 10. A cod farming cage site operated by Newfoundland Aquaventures Ltd. on the South coast of Newfoundland. (Photo courtesy of J. Moir and Andy Walsh).

Land-Based Farming

Since, as it stands now, farmed cod will be more expensive than its wild-caught counterpart, the goal of some cod farms will be the marketing of cod as an environmentally friendly product. Of course, the establishment of this market will be further enhanced if cod are grown in land-based systems. This type of system, however, will require larger starting capital for equipment and higher running costs than traditional sea cages (*e.g*. electricity used in the pumping of seawater). Careful marketing, however, may place the product on the plates of environmentally conscious consumers in Europe and around the world. In addition, better growth can compensate for at least some of this increase in cost. The use of light to prolong the growth period, before the fish gets mature is one very important factor. The possibility of keeping optimal temperatures for growth is another.

While debate continues over whether the impacts of salmon farms at sea are as serious as some would have us believe, land-based systems may be a legitimate alternative for the cod-farming industry. This may be especially true in a country such as Sweden, where availability of good farm sites, for example on the West coast, is limited. Establishing a high quality, "Organically-farmed" product may be a means of "competing by not competing" with countries such as Norway, where large quantities of cod will likely be produced in cages over the next 5 – 10 years.

Enhancement

Since the late 1800s attempts have been made in Newfoundland and Norway to enhance cod stocks through the release of larval fish (Solemdal *et al*., 1984). It has been questioned if this type of stocking has had any affect on wild stocks. High rates of mortality are likely the result of releasing larval fish into the wild and it is questionable if this effort is worth the return (Moksness & Støle, 1997). The release of juvenile fish is probably a more suitable method. There is a higher correlation between release and recruitment for juvenile fish when compared to larval releases (Legget & Dublois, 1994, Svåsand *et al*., 1998; Larsson & Pickova, 1993; Blaxter, 2000; Svåsand *et al*. 2000; Pickova & Larsson, 2003).

In order to make any recommendations with respect to Sweden, an examination of survival rates for released juveniles as well as an economic analysis of the venture, is required. In Swedish waters, which are shared by several nations and included in the common EU negotiations, one can perhaps envision a project whereby the release of juvenile fish is associated with collaboration within this field between several countries. An international agreement between the main Baltic fishery nations is needed if a plan for enhancement in the Baltic Sea is to be realised. In Denmark, a project on larval survival enhancement experiments is planned for 2004. The first tests on enhancement were performed 1991, when Eastern stock Baltic cod larvae were released in the Baltic basin within a Baltic cod project, financed by the Nordic Council of Ministers, and larvae were released in the Åland archipelago. These larvae were hatched at the Marine research Institute in Lysekil. Juveniles were also released both in the

Brofjorden at the west coast and in the Bothnian Sea with recaptures, indicating a good quality of the reared fish (Blaxter 2000; Svåsand *et al*. 2000; Pickova and Larsson 2003). The West coast of Sweden has a different situation; an enhancement programme is possibly easier to plan, since the coastal stocks are stationary to a large degree (Svåsand *et al*. 2000).

Evaluation of growth capacity and production costs

A growth model for cod

The overall most important tool needed to evaluate the potential of a new species for culture is a reliable growth model. Often we lack such a model and any prediction on growth capacity and production costs will be made on very loose grounds. Luckily there are data available on cod. Jobling (1988) compiled data on the growth of cod from various studies. The model he came up with is expressed as:

$$\ln SGR = (0{,}216 + 0{,}297 * T - 0{,}000538 * T^3) - 0{,}441 * \ln W \qquad \text{(Equation 1)}$$

where T is water temperature and W is body weight (g).

Björnsson and Steinarsson (2002) studied the growth rate of cod at various temperatures and body sizes, and were able to create another growth model for cod. The model is expressed as:

$$SGR = (0.5735 * T) * W^{(-0.1934 - 0.2001 * T)} \qquad \text{(Equation 2)}$$

This model was developed for cod within the size range 2 to 5000 g at any temperature from 2 to 16°C.

When plotting the theoretical growth rate for a 1000 g cod against temperature, the models described above give quite different results (Figure 11). The growth rate given by Björnsson and Steinarsson (2002) is higher than Jobling (1988) at low temperatures, but much lower at temperatures above 8°C.

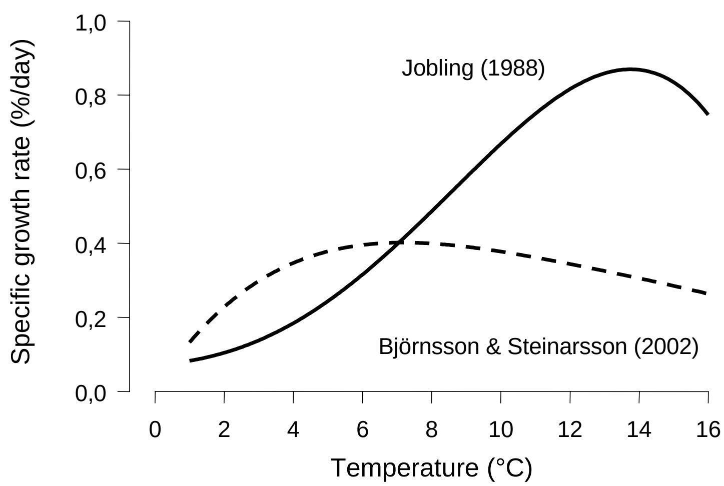

Figure 11. The relationship between temperature and specific growth rate of cod of a body size of 1000 g (data from Jobling 1988; Björnsson & Steinarsson 2002).

Which one of these two models is best suited to simulate the growth of cod in Sweden? Data on cod growth over a whole rearing cycle was obtained from the Austevoll Aquaculture Research Station outside Bergen, Norway (Ørjan Karlsen, Institute of Marine Research). As can be seen in Figure 12, the growth model presented by Jobling (1988) show a very good fit with the obtained growth data for cage reared cod. The model given by Björnsson and Steinarsson (2002) largely underestimates the cod growth at this site. In addition, a Canadian stock from the Gulf of St. Lawrence show an equal growth potential as the one predicted by the Jobling model (Lambert *et al* 1994; Lambert & Dutil 2001). We assume that the Norwegian coastal strain used in Austevoll is more similar to Swedish stocks with respect to growth and temperature tolerance than the Icelandic cod strain. Support for this is given by a study performed at the Institute of Marine Research (Lysekil, Sweden) where the growth of fingerlings to the size when release is possible (12 cm) was comparable to Norwegian coastal cod reared in Austevoll research station. For the simulation of growth, we therefore used the model described by Jobling (1988). The model should, however, be used with care in practice, as it is a risk that it either underestimates or overestimates the growth of other strains of cod in culture. More studies are needed to validate the quality and generality of the model.

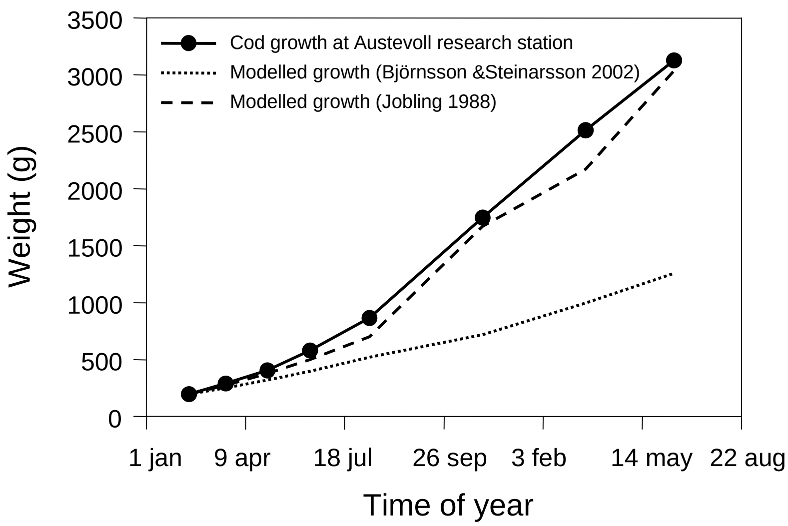

Figure 12. The obtained growth of cod reared in cages over a whole rearing cycle in comparison to theoretically estimates of growth (se text for explanation).

The growth model by Jobling (1988) is only developed within the temperature range 2 to 17°C, whereby a extra mathematical function were added to take the growth rate down to zero at 20°C.

How does cod grow in relation to other more common species in culture? A comparison between the growth model on cod and a model on rainbow trout show that the growth potential of cod is similar to that of rainbow trout (figure 13). The biggest difference is that rainbow trout has a slightly higher optimum for growth than cod.

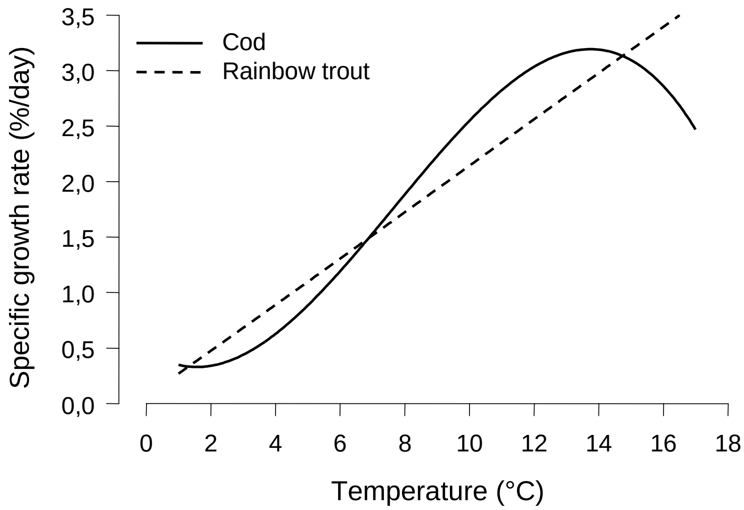

Figure 13. The specific growth rate of cod (solid line) and rainbow trout (hatched line) at different temperatures. The growth was calculated for fish of a body size of 50 g. The predictions for cod is based on equation 1 and for rainbow on a model presented by Alanärä *et al* (2001).

Energy requirements

The ability to convert the digested energy in the feed into body growth is one important aspect when evaluating the potential of a new fish species for culture. Björnsson *et al* (2001) reported the feed efficiency of cod at different body sizes. These data can be used to calculate the amount of energy needed to produce one unit of cod. The relationship body size (g) and digestible energy need (DEN, MJ digestible energy per kg growth) can be expressed as:

$$DEN = 9.937 + 1.34 * \ln W \qquad \text{(Equation 3)}$$

Due to size-related differences in metabolism and body composition of fish (Jobling, 1994), the DEN required to produce small fish is less than that to produce large fish, e.g. ranging between 10 MJ for small juvenile cod to 19 MJ for a fish of 2 kg (Figure 14). The ability of cod to convert energy into body growth is very good, actually very near the values for rainbow trout that has been selected for high growth efficiency for many generations (Figure 14). A breeding programme for cod will probably increase this ability even further.

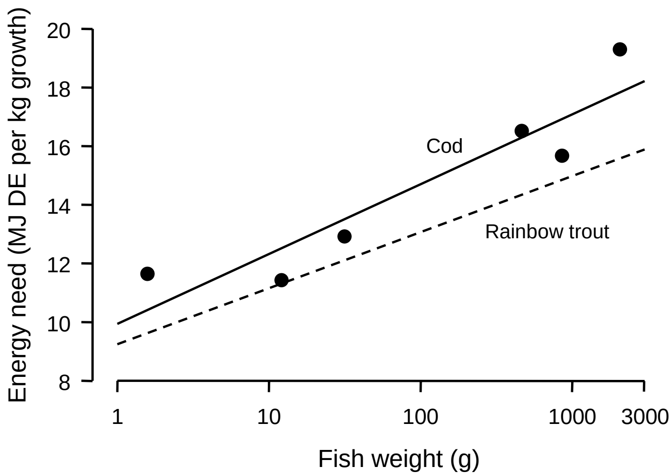

Figure 14. The relationship between fish weight and digestible energy need in cod (dots and solid line) and Rainbow trout (hatched line). Data on cod was calculated from Björnsson *et al* (2001) and data on trout from Alanärä *et al* (2001).

Feed conversion ratio

As the amount of energy needed to produce one unit of cod is similar to that of salmonid fishes, the feed conversion ratio (FCR) is expected to be within the same magnitude. Data on theoretical FCR values for different sized cod are given in Table 1. The theoretical FCR represent a management situation where all feed distributed is eaten by the fish, i.e. no feed waste. Morais *et al* (2001) obtained a FCR of 1.3 in a study on cod of the size 350 g, whereas Purchase and Brown (2001) obtained a FCR of 1.0 for 30 g fish. Hemre *et al* (2002) got a FCR of 0.84 for 750 g fish, which is relatively similar to the theoretical FCR (see Table 1).

Table 1. Examples on theoretical feed conversion ratios (FCR_t) for cod at different body sizes. A value of 0.77 means that 0.77 kg of feed is required to produce one kg of fish. The feed in this example had a digestible energy content of 19.1 MJ/kg.

Fish weight (g)	10	100	1000	5000
FCR	0.65	0.77	0.90	0.98

The theoretical FCR_t could be estimated by dividing DEN with the digestible energy (DE) content of the feed:

$$FCRt = DEN / DE \qquad \text{(Equation 4)}$$

Rearing cycle

A Norwegian study prospected the grow-out phase for cod to be 2 years in sea cages (Olafsen & Dervå 2002). They calculated that the size of the juveniles needed to be 75 g in order to reach a final weight of about 4 kg.

In most areas around the Swedish coast, there are much clearer differences between summer and winter temperatures than in Norway. The rainbow trout farming industry have adopted a rearing cycle over two growth seasons that have a length of 17 to 19 months. Juvenile fish are bought and put into cages in spring at a size of 10-100 g, and reach a size of 3-4 kg after two growth seasons. It is likely that the rearing cycle for cod in cages, at least initially, would be the same as for rainbow trout. A suggestion on the rearing cycle for cod in sea cages is given in Table 2.

Table 2. Suggested rearing cycle for cod production in cages in Sweden.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1				#	#	¤	¤	¤	¤	¤	¤	¤
2	¤	¤	¤	¤	*	*	*	*	*	*	*	*
3	*	*	*	*	*	*	*	*	*	*	*	

Egg and larvae phase. Duration: 2 months.
¤ The juvenile phase within a hatchery. The cod grow from about 4-5 mm length to a weight of 70-140 g. The fish are transferred to a sea cage plant. Duration: 11 months.
* The grow-out phase. The cod grow in cages from about 100 g to a final weight at slaughter of 2-4 kg. Duration: 18-19 months.

Moving the production into land-based farms with a more controlled environment and stable water temperatures will effect the rearing cycle. The cycle may be shorter e.g. about two years, or alternatively the same length of cycle used as for cage culture but the final weight of the cod will be larger.

In the next section, where production costs are evaluated, all examples are calculated based on the rearing cycle presented in Table 2.

Evaluation of production costs

Choice of areas for cod production

Figure 15 show the coastal areas that have been selected for simulation of growth potential and production costs. In addition, three geographically different areas in Norway were selected as a kind of reference. As for salmonid culture, Norway will probably be an important competitor in cod farming, whereby the growth potential there is important as a comparison.

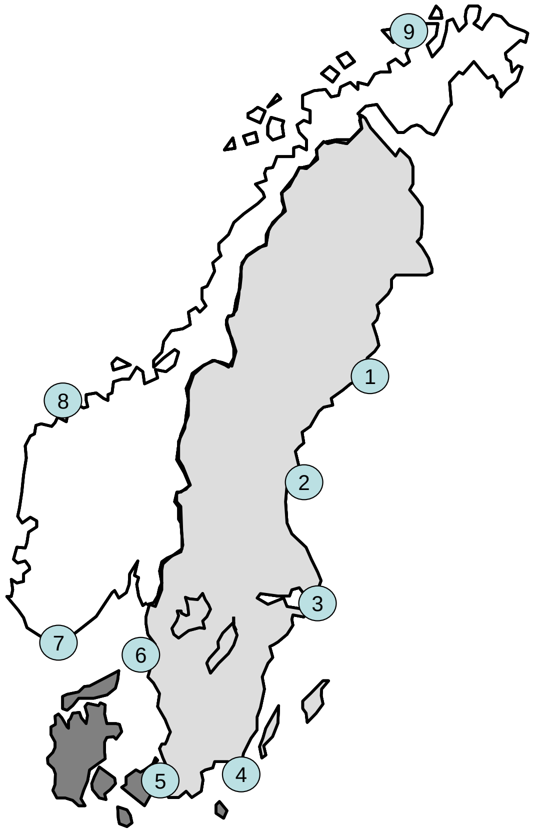

Figure 15. Map showing different coastal areas where cod production has been simulated.

Factors influencing production costs

Equation 1 was used to calculate the daily **growth**. A correction factor was included in the model, making it possible to adjust growth potential, e.g. as an effect of breeding.

The effect of **maturation** was not included in the growth calculation. As cod becomes mature, digested energy is diverted into gonads rather than to muscle growth. This slows and finally stops the weight increment of the fish. Within the data obtained by Björnsson & Steinarsson (2002) there is an indication that their growth model overestimated the growth rate of sexually maturing cod. Higher growth rates can result in higher rates of sexual maturity in cod and that they mature at a smaller size than wild cod (Björnsson & Steinarsson 2002). Much work has been performed, especially in Norway, on the effects of photomanipulation on maturity levels (Olsen, 1997; Hansen *et al.,* 2001; Hemre *et al.*, 2002). A method to achieve delay of sexual maturity in commercial situations using submersed and surface lights has been developed. This is commonly used today in cage rearing all over the world. As can be seen in figure 16, the effect of light manipulation may be dramatic and significantly increase the slaughter weight of cod.

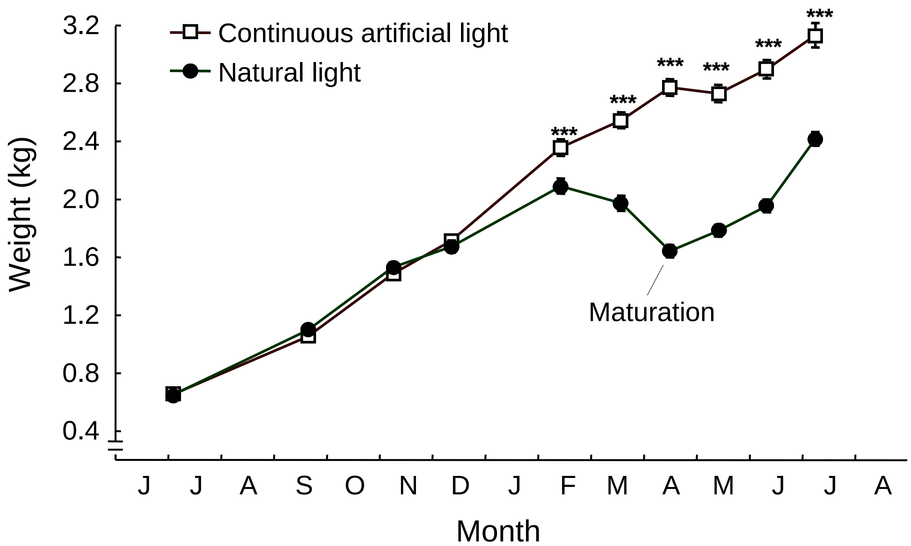

Figure 16. The effect of continuous artificial light on maturation and growth in sea cage raised cod in Norway (data from Taranger & Karlsen, submitted manuscript)

Regarding the cod populations in Swedish waters, the level of maturation is unknown. As far as we know, the only data that are available is for the eastern Baltic stock reared at the Institute of Marine Research (Lysekil, Sweden). These cod spawned during their second year (24 months post hatching at a size of approximately 1.5-2 kg (unpublished results). However, whether the coastal cod from the western fjords have the same size and spawning pattern in captivity is unknown at this time. There is no possibility today to include the effect of sexual maturation in the growth model. For the calculation of production costs we assume that fish reach their final weight prior to maturation.

Salinity: The cod in Sweden are naturally distributed from the Kvarken region in the Gulf of Bothnia, within the whole Baltic Sea and the North Sea. Within this range the salinity varies radically, from about 4‰ in the Umeå region to about 24‰ at the Swedish west coast (Table 3).

Data on **water temperature** in different regions were obtained from the Swedish Meteorological and Hydrological Institute (SMHI, The Swedish Ocean Archive SHARK (Svenskt HavsARKiv) and the Institute of Marine Research in Norway. Data on each locality represent the mean surface temperature (1 m) for several years (Table 3). To simulate the production in a land-based farm, we used a constant temperature of 10°C. In addition, data on deep-water temperatures were collected from the "Lysekil" site (station 6b) on the west coast of Sweden. These data were used to simulate land-based production using ambient water temperatures. The use of deep-water may be advantageous in coastal areas where the surface water reaches too high temperatures during the summer.

Table 3. Data on salinity and water temperature in different coastal areas of Sweden and Norway. Temperature data are given for mean winter temperatures from the first of November to the end of April, the number of days with optimal and too high (lethal?) rearing temperatures over the year. All data, except for land-based farms, are sampled at the water surface (1 m) and represents mean values for several years.

	Temperature situation			
Area/location	Salinity	Mean winter	Days with	Days with

		(‰)	temp (nov – apr)	good temp (8-14°C)	high temp (16°C)
1	Umeå	3.9	1.0	84	0
2	Sundsvall	5.1	1.6	78	0
3	Stockholm archipelago	6.5	2.8	80	47
4	Karlskrona	7.5	3.8	101	0
5	Båstad	16.8	4.0	81	82
6a	Lysekil surface water	24.4	4.0	86	76
7	Kristiansand	30.5	5.4	133	24
8	Trondheim	32.6	6.1	177	0
9	Alta	34.2	4.7	86	0
	Land-based farm with constant temperature	-	10	365	0
6b	Land-based, Lysekil deep water	-	6.6	127	0

The best Swedish temperature conditions in the surface water are in Karlskrona, with 101 days of good temperatures (between 8-14°C), no days with temperatures above 16°C, and a relatively high temperature during the winter (Table 3). The two sites on the Swedish west coast have in general rather good temperature conditions, but also quite many days with temperatures above 16°C. The sites in the Gulf of Bothnia have a quite long growing period in the summer, but very low winter temperatures. Deep water at the Swedish west coast showed promising temperatures in all aspects, long periods in the summer with good growing conditions and high winter temperatures (Table 3). The best temperature conditions for cod growth in Norway were found in the Trondheim region (Table 3).

Price on juveniles: As the production of cod juveniles is under rapid growth and rearing techniques under development, it is difficult to accurately estimate the price. Olafsen & Dervå (2002) estimated the price for a 75 g cod to be about 20 SEK per fish during 2002, but that the prize would decrease to about 9 SEK per fish within five years. Practical experiences from the production of cod juveniles in Denmark, Norway and Island indicate, however, that the price for a cod of 80 to 100 g already today is 8-10 SEK per fish. For our calculation we choose a price of 10 SEK per fish of 100 g size.

Feed cost: The cost for most of the grow-out feeds on the market today varies between 9 to 11 SEK per kg. We used a feed cost of 10.0 SEK per kg in our calculation.

Feed conversion ratio (FCR): The situation for a new species like cod is initially much better than it was for salmon in the pioneering days of fish farming. The general knowledge on feeding management is much higher and a great deal can be learnt and used from salmon experiences. In addition, the feeding technique available today is highly developed and there will probably be minor problems adapting these systems for cod. We can therefore assume that cod can be fed quite efficiently already from the beginning, but that some improvements can be made along the way. As indicated in Table 1, the optimal FCR under grow-out period ranges between 0.8 and 1.0. Practical experiences indicate that cod can be fed very efficiently, whereby we use a "safe" FCR value of 1.1 in our calculation.

The growth and **mortality** in cod was tested over a wide range of body sizes and temperatures in a study by Björnsson *et al* (2001). The results show that the highest temperature tested (16°C) had no adverse effect on juveniles (1-17 g), little effect on mediate sized fish (100 g) but severe effects on large fish (400-2200 g) (Figure 16). Their results indicate that large cod do not tolerate prolonged exposure to higher temperatures (>16°C). The findings by Björnsson *et al* (2001) must, however, be taken with some caution. Partly because the large fish (400-2200 g) were wild caught and may therefore not have been fully adapted to the rearing conditions. More important though is that practical rearing experiences from Norway (personal communication by Ørjan Karlsen, Austevoll Aquaculture Research Station, Institute of Marine Research) show that Norwegian coastal cod tolerate higher temperatures than the Island cod reported above. For example, in a study by Taranger & Karlsen (submitted manuscript) on the effect of light manipulation on maturation, summer temperatures exceeded 20°C for a couple of summer months without negative effects on growth (Figure 16) This is supported by data from Jobling (1988) showing that the optimal temperature for growth is about 13-15°C rather than 8-10°C. For cod, the preferendum zone has been shown to range between 9 and 17°C (Bøhle 1974). For the simulation of production costs, we choose a mortality rate of 15% over the whole rearing cycle.

Investment costs: Huguenin (1997) estimated that the total cage system cost including outfitting was 4.6 million SEK for 8000 m^3 of production volume. The total investment cost used in our calculation was set to 5 million SEK. The estimated cage culture equipment service life and depreciation rate varies normally between 3 to 10 years for different parts. The service life used in our calculation was set to a mean of 8 years. The rate of interest was set to 8% of the whole investment cost. The investments costs for land-based farms are much more difficult to estimate, partly because very few of them are running today and partly because there may be many different solutions on operational design (and thereby cost). We estimate the cost to be 30 mill SEK. To this figure we add a running cost of 1.5 mill SEK per year.

Results of simulation

The best results in terms of growth and production cost of the Swedish sites was found at the coast outside Karlskrona (Table 4). The cod here will theoretically grow from 100 g to 3.6 kg during the suggested rearing cycle, and the production cost is calculated to about 21 SEK per kg fish produced.

The growth at the two sites located on the Swedish west coast show relatively good growth conditions, but high water temperatures in the summer may negatively affect both growth rate and mortality. Cod in northern Sweden will grow slowly in comparison with the Karlskrona area, mainly because of the long and cold winter.

The overall best potential for cod farming was found in the Trondheim region. More or less optimal water temperatures both in summer and winter results in good growth and a productions cost of 20 SEK per kg (Table 4).

At a constant temperature of 10°C in a land-based farm, the cod will theoretically grow from 100 g to 5.2 kg under a period of 18 months and the production costs ends at about 32 SEK per kg produced fish (Table 4). Making the same calculation for a land-based farm that pumps up deep water in the Lysekil area, the final weight is 4.6 kg and costs 33 SEK per kg under the same period of time. It must, however, be pointed out that the simulations made on land-based farms in no way is optimised. Intense production will give opportunities to both shorten the growth cycle and to keep two or three cycles running in parallel. With careful planning and optimisation, the production costs for land-based farms will most likely be lower than what the rather simple calculation made here show.

Table 4. Results of a theoretical simulation on production costs, final weight and mortality in different regions of Sweden and Norway. The start weight was set to 100 g and the total production to 500 tonnes of live weight per year.

	Area/location	Production cost (SEK/kg)	Final weight (g)
1	Umeå	22,0	2385
2	Sundsvall	21,8	2505
3	Stockholms archipelago	21,7	2593
4	Karlskrona	20,6	3565
5	Båstad	22,1	2319
6a	Lysekil surface water	21,7	2560
7	Kristiansand	20,3	3935
8	Trondheim	20,2	4153
9	Alta	23,0	1927
	Land-based (10°C)	32,4	5242
6b	Land-based, Lysekil deep water	32,6	4571

Analyses of different factors affecting production costs

By separately varying growth rate, feed management efficiency (feed conversion rate, FCR), price of juveniles, price of feed, mortality, and investment costs (depreciation and interest) we could estimate which one of these factors influence production costs the most. The range of variation for each factor was subjectively estimated based on the current knowledge on costs for cod production.

For a 500 tonne production of cod in cages, production costs are most influenced by factors associated with the feed as indicated by the slope of the lines in Figure 17, i.e. FCR and the price of feed. This is not a surprise as feed costs are known to attribute to 50-60% of the total production costs. The price of juveniles also has a significant effect on production costs, while a growth improvement, mortality rates and the size of investment costs are of least importance within the range of variation tested here. The mortality rate is the factor of largest uncertainty in the simulation. However, within a limited range of mortality, in this case 0-30%, the effect of mortality on production costs is rather small. For example, if we apply a mortality rate of 30% instead of 15%, the cost of production at the Karlskrona site will increase from 20.6 to 22 SEK per kg.

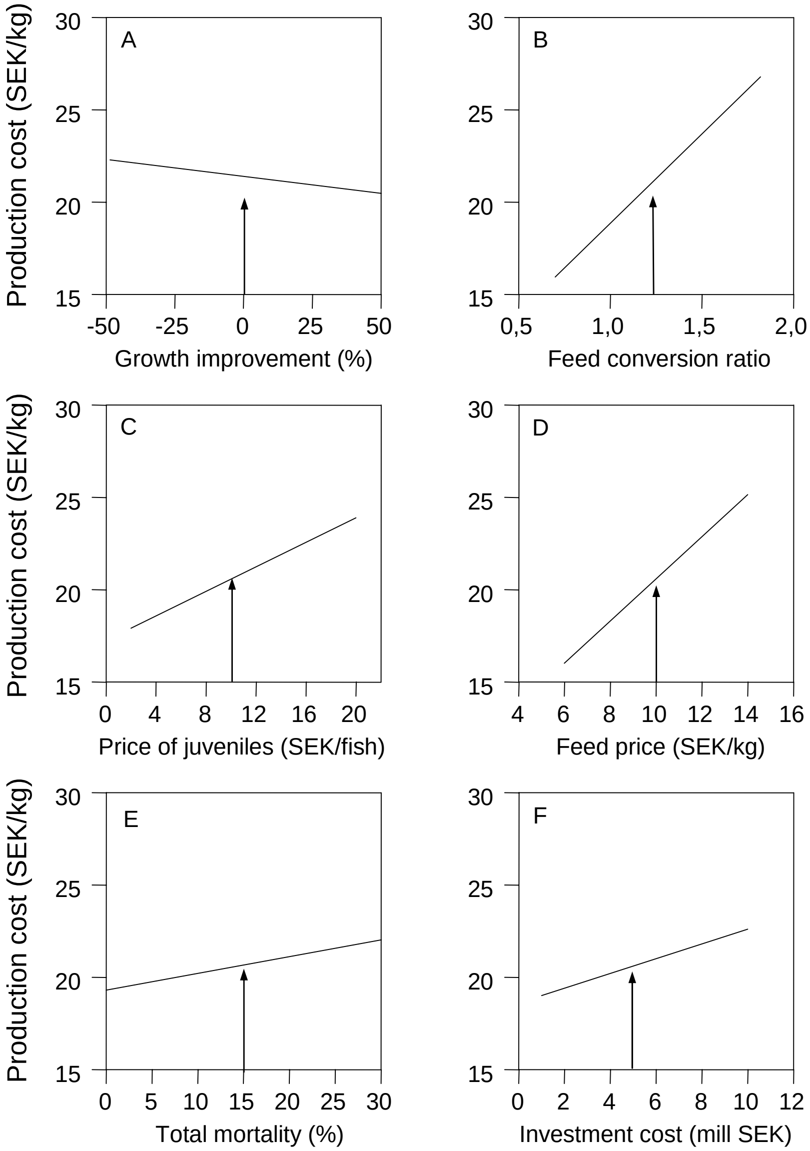

Figure 17. The relationship between (A) growth capacity, (B) feed management efficiency, (C) price of juveniles, (D) price of feed, (E) mortality, and (F) investment costs and production costs for cage farmed cod at the Karlskrona site. The default value for calculation of production costs in the Table is indicated by an arrow.

The situation for land-based farms is of course similar to that of cage farms, with the exception that investment costs increase dramatically in importance (Figure 18). The influence of investment costs is actually similar to that of feed management. Running costs within the range calculated here is of less importance (Figure 18).

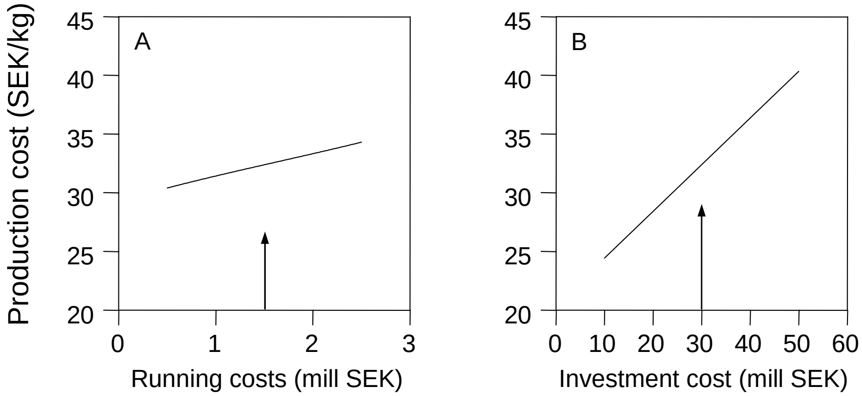

Figure 18. The relationship between (A) investment costs (depreciation and interest) and (B) production costs for land-based farmed cod.

How may production costs develop for cod?

The salmon example

The average production costs for Atlantic salmon in Norway have decreased steadily from around 60 SEK per kg in the early 1980s to less than 20 SEK per kg in late 1990 (Figure 19). In the near future, the Norwegian industry will be able to produce salmon at 16-17 SEK per kg. The major factor for this dramatic improvement in production efficiency is better management, forced by decreasing sales prices along the road. However, faster growing, later maturing and more domesticated fish have contributed substantially to decrease production costs. In addition, we must not forget that the technical development. For example, feeding systems have also proceeded substantially in the last decade, and have further reduced costs.

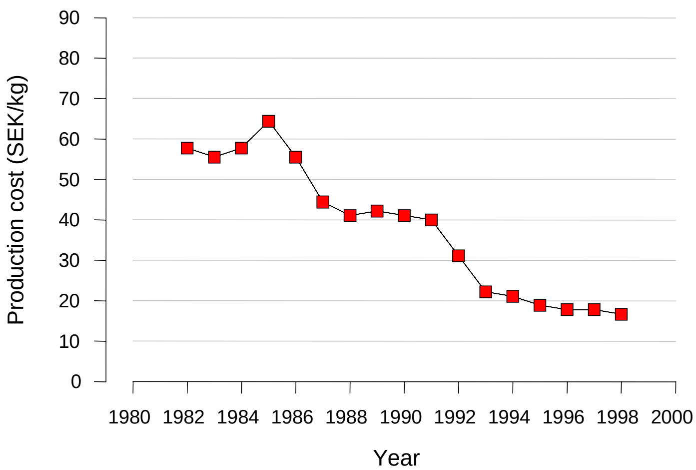

Figure 19. The development of productions costs for Atlantic salmon from 1981 to 1998 in Norway.

Breeding programme

A breeding programme is generally thought to be a prerequisite for any new species in culture. According to Norwegian experiences from the breeding programme on Atlantic salmon, the economic return is about 1 to 1.50 SEK per kg fish produced per generation. For a fish farmer producing 500 tonnes this reduces the production cost with 500 000 to 750 000 SEK. The positive effects of selection is higher growth, later maturation, better feed conversion efficiency, and general domestication effects that make the fish thrive better in culture conditions (e.g. higher stocking densities and lower stress). The improvement in growth rate is calculated to be about 10-15 % per generation (Villanueva *et al* 1996), which of coarse has a dramatic effect on production costs.

A national breeding programme on cod was initiated during 2002 in Norway by the Norwegian Institute of Fisheries and Aquaculture Research in Tromsö. This institute is designated by the Norwegian government to be the centre for cod breeding and genetics. The aim in the first round is to produce 50 families with different genetic backgrounds. Based on their performance during one rearing cycle, the best growing families (and with lowest frequency of early maturation) will be used as parental fish.

Does Sweden need a breeding programme? The answer to this question is both yes and no. In the short run, cod already seems to have a high farming capacity measured in terms of growth and energy utilisation. Some populations or strains of cod seem to have similar capacity to rainbow trout and Atlantic salmon that has been selected for generations. This fact favours the use of local strains. However, in the long run, a breeding programme is likely to be a competitive advantage over other countries farming cod. Without a breeding programme we face a risk of being out-competed after 3-5 generations of selective breeding, i.e. about 10-20 years. Different cod stocks in Sweden probably have different growth and maturation patterns and thereby varying potential for farming. For example, cod populations in the Baltic Sea and North Sea are different in terms of local adaptations (Bagge *et al* 1994), which probably is genetically based. Based on their performance in the wild, the best growing stocks could be collected and grown in a "common garden" experiment. This will give information on the best suited stock for culture and will build the basis for a breeding programme.

Future development

If we turn time 20 years ahead, what will the production situation be if we are able to optimise all of the factors discussed above? Let's assume the following for a cod farm producing 500 tonnes yearly:

- Due to selective breeding, the growth potential has increased by 50% (10-15% per generation).
- Selection and domestication processes have decreased the mortality rate over the whole rearing cycle to 7.5%.
- The price for juveniles is 8 SEK per fish.
- Feed costs remains the same, i.e. 10 SEK per kg
- Feed management has improved so that FCR is 0.9.

Under these assumptions, the costs for a 500 tonne production of cod in the Karlskrona archipelago will be about 15-16 SEK per kg fish produced and the final weight has improved from 3.6 kg to about 5 kg. In our view, this is realistic, as it follows the same trend as for the salmon industry (see Figure 19). Making the same calculation for a 500 tonne land-based farm the production cost will be about 21-22 SEK per kg.

Thus, the cost of production should not be considered a hinder when evaluating the potential of intensive cod farming. Production costs for cod will most likely follow the same development as for Atlantic salmon and rainbow trout, i.e. end up with about the same production costs within a period of time.

How much will it cost to develop cod farming in Sweden?

The costs involved in the development of a new species for culture is large. Before we speculate about this for cod, we will give a couple of examples on other species that already have gone through this process.

The Arctic charr example in Sweden

After 20 years of development, about 1000 tonnes of Arctic charr are produced yearly in Sweden. The Swedish research and development programme on charr started in 1982 and has expanded to about 20 million SEK. This cost is comparably low in relation to Atlantic salmon for example, mainly because much of the knowledge on other salmonid species could be used in the work on charr. One important experience from this programme was that the farming industry must be closely engaged within the whole process, so that the advances made quickly can be used within the companies.

About 50% of the research and development costs lay in the breeding programme on charr. This programme has been very successful and the charr today have increased their growth potential with about 50% over 5 generations.

The Halibut example in Norway

Attempts to develop halibut farming have been carried on in several countries, but the success rate has been low so far. Norway has put a lot of emphasis and money on the development of halibut farming. From the start in about 1975 until the first production of juveniles in 1990, the research and development cost was about 100 million NOK. Thereafter about 15 million per year or 200 million NOK have been invested in total, but it is still uncertain with respect to halibut farming and if it will be an economically sustainable product.

The experience and knowledge from halibut farming will, however, be useful for the development of cod farming. Much of the rearing biology and technique for larvae production are similar between the species. Thus, the starting point for cod farming is a lot further ahead due to the halibut research.

Research and development costs for cod

The research and development situation for cod is pretty much the same as it was for Arctic charr 20 years ago. A lot of the experiences made for other marine species can be used for cod farming. Thus, the costs will be within the same magnitude, i.e. about 25 million SEK within the coming 20 years (Table 5).

Table 5. Estimated costs for research and development of cod farming in Sweden.

Development area	Cost
Basic research in rearing biology (growth, maturation and behaviour)	5 million SEK
Selective breeding and genetics (5 generation)	10 million SEK
Research and development of rearing technique (feed management, brood stock keeping, vaccines, etc)	7 million SEK
Rearing trial, marketing and product development.	3 million SEK
Sum	**25 million SEK**

Site selection and environmental consequences of cod farming

Site selection

A good site for fish farming in coastal areas may not be easily found. There are a number of biological, physical and human factors that may influence the choice of site, or even hinder the establishment of a fish farm (see Alanärä & Andersson 2000). These factors are generally divided into two areas; those that are needed to successfully farm fish and those that are in conflict with the farm (Table 6).

Table 6. A summary of biological, physical and human factors that influences the choice of site for fish-farming.

Prerequisites for fish-farming	Competitive interests
The size of the water area	Landscape picture
Water depth	The human and biological value of the
Concentration of nutrients	resource (Biological diversity,
Water turnover time	recreation and outdoor activities, etc)
Sediment conditions	Source of water supply
Water temperature	Shipping trade
Water chemistry	Fishing (sport- & professional)
Wind and ice disturbance	Industry and sewage treatment plants
Infrastructure in the region	

There are, in general, no large difference in site selection between rainbow trout or Atlantic salmon and cod. As the rearing technique is more or less the same for cod and salmonids, biological and physical requirements are very similar. However, cod differ from salmonids in one important aspect; they require colder water. Cod is as described earlier adapted to rather cold waters and mortality rates may increase at temperatures above 15-16°C. In most coastal areas in Sweden, where cod farming could be suitable, surface waters may exceed this temperature during several weeks during the summer. One solution is to avoid coastal areas with too high water temperatures. This will, however, have the effect that large areas are excluded. Another way to solve this problem is to use deep water which often is much colder than the surface water. Coastal waters are often stratified during the summer, with a thermocline with colder water at some depth, usually below 5-20 meter. By choosing very deep cages that go below the thermocline the fish can thermoregulate by changing depths. Alternatively, deep water can be pumped into the cages or to a land-based farm.

The effect of cage culture on the landscape view is dependent on many factors where the size and location of the farm is the most crucial. How people feel about a new business and its usefulness or how beautiful the landscape is varies quite a bit, whereby peoples attitudes and appraisal often play a key role in the establishment of a new fish farm. Experience from earlier prospects of cage farms in Sweden show that impacts on the landscape view often is the single most important factor that evokes protests from the people living nearby or those using the area for recreation. It is therefore important to avoid such conflicts, for example by avoiding coastal areas with high population densities or those with a rich outdoor life. In addition, moving the farms to more off-shore areas will reduce the impact on the coastal landscape.

The situation for land-based farms is somewhat different. One prerequisite to build a plant on land is a building permit. Land-based cod farms need access to large amounts of salt water, whereby it is advantageous to be located near the shore line to avoid large pumping costs. Building permits on sea front sites may be a limiting factor for land-based cod farming in Sweden. One solution would be to use existing buildings, e.g. old industrial buildings. Similar to a cage farm on the water, the effect of a land-based farm on the landscape will vary largely depending on the infrastructure in the area. A large land-based fish farm near the sea side in an area with lots of summer houses and tourist activities will cause much more conflicts then a farm located in an industrial area.

Environmental consequences of cod farming

The farming of cod has the potential to alter the environment in several ways: either on a short-term basis (increased odour, noise and visual pollution), or by more permanent disruption (physical and biological changes). The main environmental consequences of fish farming are:

- The effects of organic materials and dissolved nutrients from fish farms
- The effects of cultivated fish on wild stocks (genetic and ecological risks)
- The transfer of disease between cultivated and wild stocks
- The discharge of medicines and chemicals into the environment

The environmental effects of fish farms in general are well covered in several textbooks (see for example Pillay 1992, Baird *et al* 1996, Willoughby 1999, Black 2001). In this section, only specific issues related to cod farming in Sweden will be discussed.

Organic nutrient discharge

Particulate organic material is that which is derived from living organisms and accounts for most of the pollution around fish farms. This organic material is primarily fish faeces and waste feed. It can accumulate beneath poorly sited sea cages, or in shallow areas or localities with insufficient tidal and current action.

Faeces are the remaining undigested material from the eaten feed, the composition and consistency of which depends upon the type and quantity of feed given. It is not as serious a polluting agent as waste feed as a result of its slow sinking rate and fibrous nature, which allow it to float and be widely dispersed.

Even though the aim is to feed the fish without waste, some waste will likely occur. It accumulates along with faeces on the seabed. Unlike fish faeces, waste feed sinks rather rapidly and may accumulate on the bottom within the vicinity of the farm. Feed that sinks out of the cage may, however, not be wasted. Depending on the wild fish fauna and its density around the fish-farm, we can assume that a substantial part of the feed waste will be eaten by wild fish. A similar situation may be the case for fish faeces. Thus, all the organic material does not sink to the bottom, but is instead taken up directly by the biological system.

In addition to the particulate organic material, various dissolved substances are also discharged into the environment from excretory products from the gills and fish urine, fish faeces and seabed sediments. Of particular importance are the elements nitrogen (N) and phosphorus (P). If the concentration of nutrients in the effluent water leaving the farm becomes too high, large-scale eutrophication effects can result. If the critical nutrient load is exceeded, algae blooms may occur.

The eutrophication effect that a fish-farm can give rise to locally will be dependent on two main factors: the current concentration of nutrients in the water, and the water turn-over time. On sites with low concentrations of nutrients and a high rate of water exchange, negative effects of fish-farming will not likely occur.

The limiting growth factor for primary producers (algae, plants, etc) in the coastal areas of Sweden is either phosphorus or nitrogen. In general, phosphorus limits growth in the Gulf of Bothnia, whereas nitrogen is the limiting factor in the Baltic Sea and North Sea.

In recent years, many ***sea cage farms***, new or ongoing, are situated in areas with strong currents and suitable seabed topography, which significantly reduce the build up of waste sediments. Alternatively, the cages can be rotated or moved to another site that allows the seabed to recover naturally. In many countries, including Sweden, new sites are somewhat limited and there is a growing trend to move into more exposed offshore areas that have better water exchange and where the conflicts with other users are fewer. However, due to the stronger winds and waves often found offshore, fish-farming equipment must be redesigned to withstand harsher conditions. Such rearing systems are now available, although the cost is comparably high in relation to traditional ones.

Land-based fish farms have a large advantage over sea cages in that the discharge of nutrients can be filtered and treated. In a modern, land-based fish-farm, most of the particulate organic material can be removed from the outgoing water and thereby drastically reduce the environmental impact. The treatment of dissolved nitrogen is more difficult as the removal is dependent on biological filters, i.e. some organisms (bacteria, algae, plants, etc) taking up the nitrogen. However, new techniques are under development, *e.g*. for municipal sewage treatment plants, which will make nitrogen removal possible to some extent.

One way to reduce the environmental impact from sea cages is to use a ***fully enclosed cage system*** (Figure 20). In such enclosed systems the net cage is replaced with a flexible plastic bag (see Kelly & Elberizon, 2001). Water is circulated artificially, entering the bag at the top and flowing out through a sump outlet in the base. This outlet presents the opportunity for treatment of particulate organic material to occur. However, no opportunity exists for removal of soluble wastes like nitrogen on cage systems. As most (90-95%) of the nitrogen is in a soluble form, enclosed cages have nearly the same environmental impact as traditional open cages in sea areas where nitrogen is the limiting growth factor. A fish-farming company is traditionally limited in its infrastructure expenditures and the costs associated with enclosed systems may exceed the financial capacity of the producer. The decision to use enclosed cage systems must be evaluated against land-based rearing systems. As the cost for enclosed cage systems reaches the level of land-based farms, the latter may, under some circumstances, be favourable as the working conditions are better and wastewater treatment can be more easily applied.

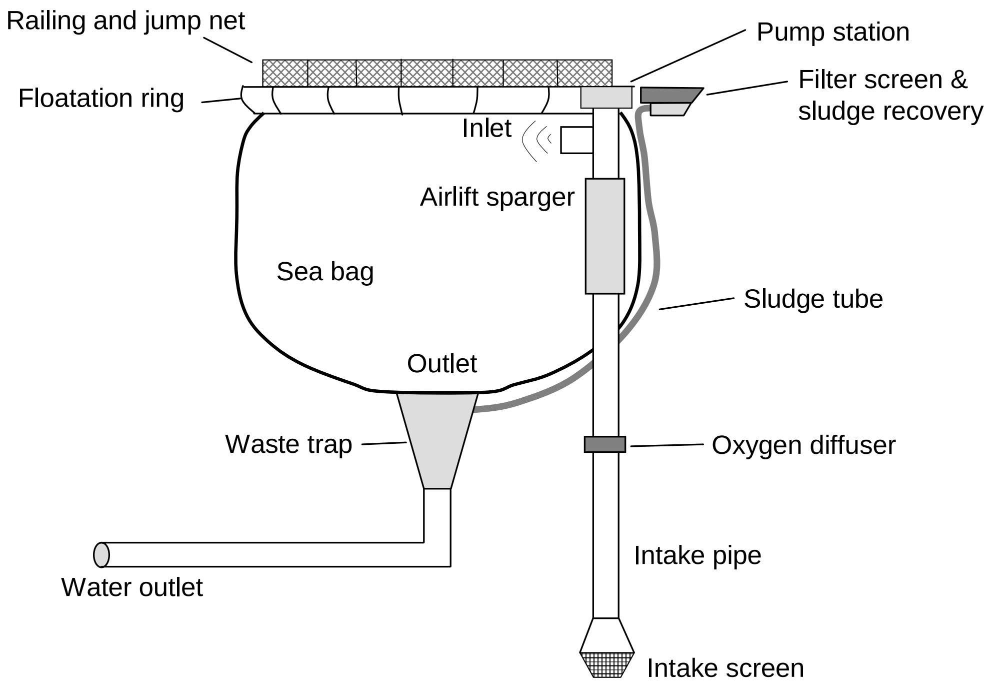

Figure 20. Schematic diagram of a fully-enclosed cage system (redrawn after Kelly & Elberizon, 2001)

Nutrient load

In Norway, during 1988, the amount of nitrogen discharged for each tonne of fish produced was approximately 90 kg. These estimates were revised in 1994 to 50 kg per tonne of fish produced (Willoughby 1999). The same trend has been observed in Swedish rainbow trout farms, decreasing from about 120 kg in 1980 to 50 kg per tonne of fish produced in 1995 (Jonsson & Alanärä 1998).

The phosphorus load from Nordic cage farms in the beginning of 1980 was about 30 kg per tonne of fish produced. Due to better feed management, lowered phosphorus content in the feed and increased energy content, the load has been reduced to 5-7 kg per tonne today (Jonsson & Alanärä 1998).

There are no data available on the nutrient discharge from cod farms, but as cod seems equally as efficient as salmonids in utilising the feed, the load should be within the same magnitude, i.e. 50-60 kg nitrogen and 5-7 kg phosphorus per tonne of fish produced.

Environmental policy and the prerequisites for starting coastal fish farms in Sweden

The environmental situation in the main Baltic Sea and North Sea is strained, with a nutrient discharge that exceeds the critical load in many areas. Local problems with eutrophication are mainly found in these sea areas, whereas the situation in the Gulf of Bothnia is much better with no or few signs of eutrophication.

The Swedish government have approved 15 goals on environmental quality towards a sustainable ecological society within one generation. One of these goals, “no eutrophication”, deals with the environmental situation in freshwater and sea water. As the main goal for coastal and open seawaters, the government has stated that the concentration of nutrients should correspond to the prevailing situation during the 1940s. In addition, the nutrient load to the sea should not cause any eutrophication effects. The main message here is to reduce the load of nutrients to the sea drastically. This will of course influence any new activity that may discharge nutrients to the sea. Most applications on new fish-farming permits or increased production of existing ones have been rejected in the last 10 years. For example, the verdict on one application for a fish-farming permit in the Stockholm archipelago was finally decided in the district court of Stockholm. The application was rejected with the motivation that new or increased fish farming activities should not be allowed, as the environmental impact on the Baltic Sea will be too large. As in other similar cases, this verdict may form a precedent for future trials.

The conflict between environmental protection goals and new activities like fish farming that add nutrients to the sea is to a large extent a matter of scale. On a large national scale, Sweden aims to reduce the overall environmental impact on the sea, whereas on the local regional scale people seek different ways of making an income by using natural resources like the sea. The different interests are difficult for the regional environmental protection agency (Länsstyrelsen) to handle and when the principle of cautiousness is applied, most applications for farming permits are rejected in favour of national environmental goals. The knowledge on site selection based on the current nutrient situation and water turn-over time is, however, relatively good today, and fish farms can be located to areas where the local environmental effect will be low.

What consequences will the current environmental situation have on fish farming in general and cod farming in specific? Here are some possible scenarios:

1. It will be difficult to get farming permits in the Baltic Sea and North Sea, especially for fish farms with a yearly production exceeding 100 tonnes per year.
2. Cod farming in the Baltic Sea and North Sea may only be admitted for political reasons, where environmental issues are sub-ordered, other important issues like regional [development] policy, or for conservation reasons to save the wild cod.
3. The environmental situation in the Gulf of Bothnia is relatively good and should not hinder further development of fish-farming activities.
4. In land-based farms, most of the particulate organic material can be filtered off and removed from outgoing water. Dissolved organic material can be treated, but it is unsure if the techniques available today are cost effective enough. The load of dissolved nitrogen may therefore be a problem in some coastal areas.
5. Fully enclosed cage systems are a promising new technique where a lot of the particulate material can be removed. However, as for land-based systems, dissolved nitrogen will be problematic.

The effects of cultivated fish on wild stocks

The choice of cod stock and genetic risks

The rapid growth of fish farming has raised questions about possible genetic impact on wild populations (Maitland 1986). Cultured fish often represent genetically exogenous populations or crosses between them that have been subjected to selective breeding and/or domestication programmes. This means that cultured fish, after several generations, are genetically different from wild populations and can threaten biodiversity (Hindar *et al* 1991).

Atlantic cod is a widely distributed species, extending from northern arctic waters to as far south as the Georges Bank and the Celtic Sea (Brander 1994). As for many other species, this has lead to local adaptations and genetic differences between stocks (Møller 1968, Ruzzante *et al* 1999). Genetic differences in growth have been reported for Norwegian cod stocks during all life-stages (Svåsand *et al* 1996, Otterlei *et al* 1999).

Kapuscinski & Brister (2001) presented an evaluation scheme for the probability of interbreeding between farmed and wild fish. The genetic risks of cod farming are evaluated in Table 8 using this scheme.

Table 8. Evaluation scheme for the genetically risks with farmed cod.

Factor	Evaluation
Entry potential	
frequency of farmed fish escaping at different seasons	The frequency of escaped Atlantic salmon in Norway was 477 000 fish in 2002, corresponding to about 0.1% of the total amount produced fish (The Directorate of Fisheries, Norway). Fish escape from cages damaged in storms, through holes in the nets caused by damage or accidents, or during handling. As indicated by the salmon figures, the risk of a large number of escapees is rather high in sea cages depending on the volume of production. The same risk is assumed for enclosed cages. The risk for escapes from land-based farms is much lower and can theoretically be reduced to zero.
travel distance to suitable areas for spawning, which may harbouring wild fish	The travel distance may be very short. In fact, fish-farms may be located at or very near the spawning areas of wild fish. Even if wild cod is missing, escaped farmed cod may be able to spawn with each other in the vicinity of the farm. In addition, farmed cod may spawn within the farm and eggs may easily be spread out to surrounding waters. The two latter cases forms a high risk as the offspring of farmed cod can grow to reproductive size and spawn with wild cod.
probability of surviving in transit to these areas	As the transit distance may be relatively short, the probability of survival is high.
Introgression potential	
probability of surviving to reproductive stage	McNeil (1991) estimated that less than 5% of the approximately 5 x 10^9 hatchery-reared and stocked juvenile salmonids survive to adulthood on a worldwide basis. The probability of farmed juvenile cod to survive to reproductive stage is probably rather low. The risk increases, however, with the age of the fish, and large cod near maturity probably forms a much higher risk than juveniles.
degree of similarity in reproductive development	No difference between farmed and wild cod is to be expected.
timing of spawning between aquaculture and wild fish	Depending on growth manipulation, by temperature and/or light, the maturation in farmed cod may be out of phase compared to wild fish. However, without any manipulation, the timing of spawning should be similar between wild and farmed cod.
mating behaviours between aquaculture and wild fish	Reproductive fitness in the escaped fish is in general lower than in native wild fish because of the behavioural deficiencies at spawning (Youngson *et al* 2001, Volpe *et al* 2001). Even though successful spawning may be limited, escaped cod is likely form a risk depending on the number of escapees.
fecundity and gamete viability of aquaculture escapees	No difference between farmed and wild cod is to be expected.

Based on the risk assumptions made above, we believe that the genetic risks are somewhat larger for farmed cod than for salmonids. The main reason for this assumption is that cod may have shorter travel distance to suitable spawning areas, and may in fact spawn within the farm. How can the genetic risks of cod farming be reduced or avoided? The main measures are suggested to be:

- Use sea cages developed for off-shore farming. The risks for accidents due to storms are reduced.
- Farm cod in land-based systems where the risks for escapes more or less can be eliminated.
- The timing of harvest and slaughter should be well ahead of fish starting to mature. No mature fish in cages! Broodstock holding should be avoided in net cages.
- Reproductive sterility is recommended as a future key to eliminate the genetic potential of escaped fish, e.g. triploidy, all female, etc.

The probability of loss of genetic variation increases as the genetic distance between the aquaculture and wild populations increases (Kapuscinski & Brister 2001). Estimation of this probability requires knowledge of the genetic population structure of wild cod with which the farmed escapees could interbreed, as well as the genetic distance of the populations from the farmed stock. To avoid similar problems as those with farmed Atlantic salmon, researchers in Norway plan to screen the whole genome of cod. This will give basic information for risk assessment in the future. The whole work is planned to take 5 years.

Sweden is in the same situation as Norway when it comes to genetic risks. We need more information on local adaptations and genetic differences between wild stocks in order to handle future problems with farmed cod. It would be advantageous to collaborate with the Norwegian study on the cod genome.

For more specific recommendations on how to handle the genetic effects of farmed fish on wild stocks see Hindar *et al* (1991), Utter *et al* (1993) and Brister & Kapuscinski (2000).

Ecological risks of escaped cod

Large numbers of escaped fish can cause overcrowding in the habitat of natural populations, such that their long-term productivity is reduced (Altukhov & Salmenkova 1987). Escaped salmon for example can migrate to streams and rivers and compete with the wild stock for food and spawning sites.

Cod in the wild, however, do not compete for food and habitats in the same way as salmonids. Ecological risks due to competition will most likely be small in cod, especially as long as the wild stocks are far below their carrying capacity.

Transfer of diseases between cultivated and wild stocks

In Sweden two main organisations deal with diseases in cultured and wild fish; Fiskhälsan (FH, Ulf-Peter Wichart) and The National Veterinary Institute (SVA, Anders Hellström). They were asked some specific questions on future cod farming in Sweden and potential problems with fish diseases. More detailed information on cod farming and diseases are given by SVA in supplement 1 (in Swedish).

Do cod get the same diseases as salmonid fish?

FH: Yes. Viruses, especially Viral Haemorrhagisk Septikemi (VHS). The bacteria vibriosis is very common. Some parasites may infect cod, but not classical sea lice.

SVA: We know that the following diseases may cause problems for cod farming, some that are the same as for salmon, Viral Haemorrhagisk Septikemi (VHS), Infektiös pankreasnekros (IPN), Viral Erythrocytisk Nekros (VEN), and Piscine Erythrocytic Necrosis (PEN). Vibrio salmonicida, Cod ulcus-syndrom (CUS), Gyrodactylus spp.

Is there any difference in how diseases are spread between wild and farmed populations?

FH: There are no principal differences.

SVA: The influence by farmed cod on wild populations is the same as for salmonid culture. There are also diseases that may be transformed from cod to salmonid fish and vice versa.

Are there any specific threats, problems or restrictions with cod farming?

FH: Salmonid species should not be reared together with cod in the same farm.

SVA: From a disease prevention point of view, the same restrictions and cautions should be used as for salmonid fish farms.

Medication

The vast majority of bacterial diseases of farmed rainbow trout in Sweden have been brought under control during the recent years. This is reflected by negligible antibiotic use for 1999 (Figure 21).

It is likely that the antibiotic use in cod farming will, in the same way as for salmonids, be kept low. Juvenile cod vaccination can be performed using the standard procedures.

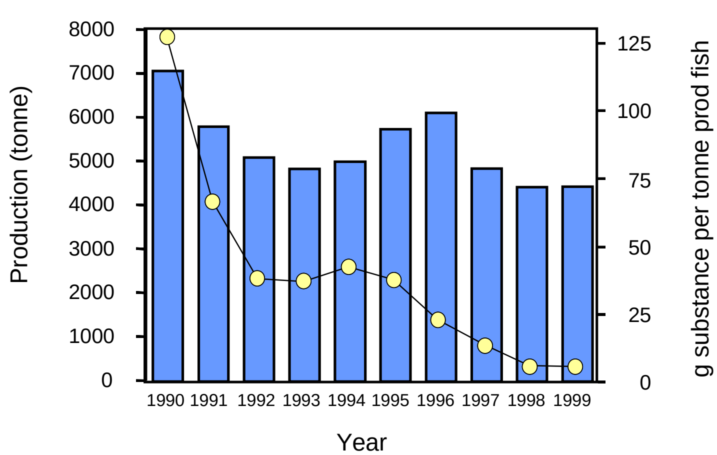

Figure 21. Antibiotic use (circles and line) and production (bars) of rainbow trout in Sweden from 1990 to 1999.

Current status in other countries

Norway

In order to get an idea of the experience and status of cod culture in other countries, experts in each country were contacted for information. Consultations were made with Jørgen Borthen (Norsk sjømat) and Ørjan Karlsen, Havforskningsinstittutet in Norway in order to gain an understanding of the status of the industry there.

Currently, Norway has about 17 cod hatcheries (3 producer ponds and 17 hatcheries) as well as hundreds of cod farming permits, ready to grow cod in sea cages. It appears that Norway is about ready to lead the world in the development and production of cod, mostly in sea-based cages.

Farmers buy cod juveniles of 50g for approximately 9 SEK and feed costs are currently at about 9 SEK per kg. The approximate production cost of cod is 23 SEK per kg while the selling price is 23-26 SEK per kg. This price is highly varying depending on season and the general situation.

Jørgen Borthen did not mention any serious disease outbreaks but suggested that with high summer temperatures bacterial diseases might become a problem in the future. However, this problem has not occurred as of yet.

The usual problems associated with large livers in farmed cod were tackled through the suggestion that, with proper cod nutrition, cod liver can become a valuable by-product of farming, further increasing the total sellable yield. In addition to cod livers, Jørgen Borthen mentioned cod roe and heads as valuable by-products.

When asked about research areas, Jørgen Borthen stated that research is ongoing in many areas with respect to cod farming in an attempt to solve some of the difficulties with farming this species. It was difficult to say where most research was being performed but photomanipulation to control maturation and nutritional needs of cod are two examples. In general, research on cod farming had increased in the past years.

Denmark

As of winter 2003, Denmark had developed a plan of action in the possibilities for cod farming in Denmark. The first part of that plan involved the examination of the current literature and expertise in cod farming in order to get a better understanding of the processes and especially how they can be adjusted to Danish conditions. The second part involved the utilization of this information in the development of a concrete project in the testing of land-based cod farming in Hanstholm. The goal of this project was the rearing of 100 tons of cod in recirculating systems. Analysis of technological, scientific, economic, and marketing questions during this project were to be examined.

Dr. Josianne Støttrup (Ministry of Food, Agriculture and Fisheries, Danish Institute of Fisheries Research) was contacted to answer some questions with respect to the current status.

Dr. Støttrup stated that the biggest problem facing the future of cod farming in Denmark is the ability to attract investors. Currently, the Danish market price for cod is about 31-43 SEK per kg for high quality (Grade V) wild fish. Production costs for farmed fish are estimated to be as follows (2003):

- 0.06 SEK per hatched larvae
- 5 SEK for 5g juveniles
- 10 SEK for 80g fish
- Final sale price at about 35 SEK per kg

Based on this information we see that raising cod to market size in Denmark has borderline economics right now. Dr. Støttrup did mention, however, that Danish efforts would be put into the rearing and selling of mainly juveniles. Using recirculation systems it was calculated that juveniles could be produced cost-effectively. This will be tested in a pilot scale hatchery at a later date in order to confirm projected costs.

Faroe Islands

The Faroes have a long experience with extensive cod production. Using wild-caught cod transferred to cages and fed using herring or capelin, has led to positive results. One of the biggest problems facing the development of a cod farming industry on the Faroes is space. Salmon farming sites takes up nearly every possible bay and so little room is left for expansion. Some interest has been shown in the use of land-based systems and also in the development of larval hatcheries for the production and sale of juvenile cod.

Iceland

Dr. Björn Björnsson (Marine Research Institute, Reykjavik, Iceland) was contacted in Iceland. Dr. Björnsson has been doing work on cod for the past 10 years or so and is considered an expert in the field.

Last year 250 000 juveniles were produced intensively under hatchery conditions. These will be raised in a land-cased facility for the first winter and then moved to sea cages for ongrowing to market size (3-4 kg). In addition, 500 000 juveniles (2-3 g mean weight) were collected from the wild and 500 tons of 1-2 kg cod were collected for ongrowing in sea cages.

Farmers wishing to buy juveniles weighing about 10 g from a hatchery will pay approximately 5 SEK each. They can later sell market-sized cod for around 21 SEK per kg round weight. Icelandic farmers have experienced no major disease outbreaks and concerns cited in some other countries with respect to large livers have not been a real problem for Iceland.

In the sea, cod are raised in large circular cages with two floating rings. The sizes of these cages vary depending on local conditions and the size of the farm. Wild-caught cod for ongrowing are usually fed with whole fish such as capelin and herring. This wet feed costs between 0.75-4 SEK per kg. Hatchery-reared individuals are fed using dry, pelleted feed costing about 10.6 SEK per kg. This feed is produced in Iceland and the macronutrient makeup is usually 15% fat, 62% protein, 14% carbohydrate and 9% moisture. Feed conversion ratios vary depending on the feed type used. Values as good as 3 have been obtained using capelin and herring while values of around 1 have been had using dry feed.

Dr. Björnsson also feels that, judging by the increase in research for cod farming, production will likely increase. Research has at least doubled in the production of juveniles, selective breeding, and growth studies.

United Kingdom

Jim Buchanan of the British Marine Finfish Association (BMFA) was contacted as a contact in the UK. He referred us to various publications from the BFMA, which give information on the current status. The BFMA predicts that cod farming in the UK will provide major economic benefits to coastal communities and will provide a boost to the hard-hit fish processing infrastructure desperately looking for supplies, particularly for smaller businesses who rely on a high quality fresh fish, rather than frozen.

Current UK cod production will be about 90 tonnes this year (2003), but the BMFA believes that in 10 years time total UK farmed whitefish production (mainly cod, haddock and halibut) will be worth 1.400 mills SEK to the Scottish economy, employing 600 people in fulltime, high quality jobs. Of this, annual farmed cod production is expected to rise to over 3,500 tonnes within the next four years and could soar to around 30,000 tonnes within the next 20 years.

Cod is viewed as a species with good future potential in the UK. Marine Farms ASA recently formed a joint venture with Stirling University's Institute of Aquaculture to develop Scotland's first commercial cod hatchery at Machrihanish on the Mull of Kintyre. Planned production at this facility is 1.2 million fish per year. Richard Slaski, adviser to the BMFA stated, "The opening of the hatchery is a major step towards the industry meeting the strategic targets which BMFA has set for cod cultivation in Scotland. The association believes there is an exciting niche market opportunity for up to 30,000 tonnes per annum of cod production from aquaculture, which will play its role in helping the aquaculture industry to diversify, and in maintaining supplies of fish to the other parts of the UK seafood industry."

As has been seen in other countries, a lack of working capital in the aquaculture industry is stifling the development of the farming of cod, according to Alastair Barge, chairman of the British Marine Finfish Association (BMFA). Positive aspects of marine fish farming include the low requirement for fish oil. While they do have a high protein requirement, this may be partially supplied by plant protein - an issue currently being researched in the UK. In addition, the fish do not appear to suffer from lice as salmon does. Vaccines are already available and a large infrastructure is in place to deal with health and environmental issues - expertise which did not exist in the early days of salmon farming.

Canada

Dr. Joseph Brown's lab in Newfoundland, on the East coast of Canada has been conducting research in cod farming, and especially egg and larval development since the early 1990's. As part of this project I travelled to Dr. Brown's laboratory in the Ocean Sciences Centre of Memorial University of Newfoundland to discuss cod farming in Canada (Figure 22).

Dr. Brown has been a researcher at the OSC for over 20 years and is currently the acting Director of this large facility. His program is composed of both fundamental and applied research. The applied area of research is aquaculture. Interests in this area are focused on developing new species for cold-water aquaculture and improving culture techniques for various cold-water species. During the period since the closure of the cod fishery in Newfoundland (1992), Dr. Brown and colleagues from Memorial University of Newfoundland (MUN) have been conducting groundbreaking research in the development of larval culture of cod. They seem to have resolved most of the serious problems associated with larval survival and weaning onto pelleted feed and what remains now is the grow-out of this fish. As part of an Atlantic Innovation Fund (AIF) in Canada, Dr. Brown and his colleagues will receive 23 mills SEK per year over a five-year period, in addition to funding from other public and private sources, including the Canada Foundation for Innovation. It seems that in Canada as well, the push is on for the development of cod farming on the East coast.

A new 1300 m^2 aquaculture building at the Ocean Sciences Centre was built in 1999 and allows for high quality technical work on marine species (Figure 23). For larval cod there are freshwater egg incubators (re-circulation and flow-through) and up-welling silos from 0.5 to 12 m^3 for marine fishes. A critical component of the new facility is a sea water system designed to deliver high quality, temperature controlled, flow through and re-circulating water. There are areas for broodstock conditioning, hatchery and nursery operation, first feeding, and on growing. Live food production facilities have daily production capabilities of 1000 L algae, 1 billion rotifers, and 500 million *Artemia*. Here seawater and freshwater tanks ranging from 0.5 – 12 m^3 are at the disposal of the researchers, again with full temperature, light and flow control. Sea cage research is done in co-operation with commercial cod growers in Bay d'Espoir, Newfoundland.

Figure 22: The Ocean Sciences Centre and it's Aquaculture Research and Development Facility (ARDF) to the far left.

There are currently 57 cod farming licenses issued for Newfoundland (AquaGIS, 2003). Of these, 49 are currently in production, utilising mainly wild-caught cod from areas where the moratorium is partially lifted. These produce collectively 207 tonnes, worth approximately $525 000 CDN (AquaGIS, 2003). This production would increase dramatically with the availability of juveniles from hatcheries and so plans are in the works for one of the largest hatcheries in the world in Bay Roberts, Newfoundland. Unfortunately this facility had not yet opened while I was in Newfoundland but is scheduled to open in January, 2004. It will produce up to 10 million 10g fish per year and provide farmers with a reliable source of juveniles for grow-out. During the first year, production is anticipated to be between 200 000 and 500 000 fry. The vision put forth by the government is to produce 15 000 to 30 000 tons of market sized cod by 2010, and to put cod farming in Newfoundland on the same economic level as salmon farming in Scotland.

Figure 23: Large broodstock tanks in the Aquaculture Research and Development Facility of the Ocean Sciences Centre, St. John's, Newfoundland.

The major goals of the current research plan for cod farming using funding from the AIF can be summarised thus:

1. Optimal transfer size of weaned juveniles to sea cages: 1-3 years.
2. Stocking density, feeding frequencies, feed ration analysis and physiological parameters: 1-3 years.
3. Maturation of fish in cages and development of protocols to address problem 3-4 years
4. Site analysis and environment: 2-3 years.
5. Development of cost-effective, cage on-growing methods: 3-4 years.
6. Reduced health problems through effective and environmentally friendly methods and treatments: 3-5 years.
7. Cage trials of juveniles from photo manipulated broodstock: 2-4 years
8. Cage trials of juveniles from superior strains of broodstock: 3-5 years
9. In addition, the federal Department of Fisheries & Oceans (DFO Newfoundland & Labrador Region), in conjunction with an industry partner, Newfoundland Aquaventures Ltd., and in collaboration with the Ocean Science Center of Memorial University, is engaged in a cod broodstock research and development project at the Aquaculture Research and Development Facility (ARDF).

Asked to choose the main problem areas for the development of cod farming in Newfoundland, Dr. Brown said that it was difficult to choose just one. He stated that on-growing in cages is where they have the least information so cage work is critical and in that category we have: feeding strategies (based on growth during warm and sub-zero conditions), early maturation, and disease and parasite monitoring. Dr. Brown also mentioned that in the not so distant future, a broodstock development program will have to be implemented. Hatchery production has been consistent but survival rates are still only at about 5% from egg to juvenile so work is still required there as well. All in all there appears to be a bit of work left before cod farming will be as fully understood and as efficient as the farming of traditional species such as salmonids.

References

Alanärä, A och Andersson, T. 2000. Kriterier för lokalisering av vatten lämpliga för fiskodling. Vattenbruksinstitutionen, Sveriges Lantbruksuniversitet, Rapport nr 26.

Alanärä, A., Kadri, S. and Paspatis, M. 2001. Feeding management. In: *Food intake in fish* (eds. Houlihan, D., Boujard, T. and Jobling, M.). Blackwell Science, Oxford.

Altukhov, Y. & Salmenkova, E. 1987. Stock transfer relative to natural organization, management and conservation of fish populations. In Population Genetics and Fishery Management (Ed. By N. Ryman & F. Utter), pp. 333-343. University of Washington Press, Seattle.

AquaGIS. 2003. Aquaculture Geographic Information System, Department of Fisheries and Aquaculture, Newfoundland and Labrador, Canada. (www.aquagis.com).

Bagge, O. 1981. Cod. *In:* The Baltic Sea. A. Voipio (Ed). Elsevier, Amsterdam. pp. 312-319

Bagge, O., Thurow, F., Steffensen, E. and Bay, J. 1994. The Baltic cod. In: The Baltic Sea (ed. A. Voipio), pp312-319. Elsevier, Amsterdam, The Netherlands.

Baird, D.J., Beveridge, M.C.M., Kelly, L.A. & Muir, J.F. 1996. Aquaculture and water resource management. Blackwell Science Ltd.

Baskerville-Bridges, B., & Kling, L.J. 2000a. Larval culture of Atlantic cod (*Gadus morhua*) at high stocking densities. *Aquaculture* 181, 61-69.

Baskerville-Bridges, B., & Kling, L.J. 2000b. Early weaning of Atlantic cod (*Gadus morhua*) larvae onto a microparticulate diet. *Aquaculture* 189, 109-117.

Björnsson, B & Steinarsson, A. 2002. The food-unlimited growth rate of Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 59: 494-502.

Björnsson, B., Steinarsson, A., & Oddgeirsson, M. 2001. Optimal temperature for growth and feed conversion of immature cod (*Gadus morhua* L.). *ICES J. Mar. Sci.* 58, 29-38.

Black, K.D. 2001. Environmental impacts of aquaculture. Sheffield Academic Press, Sheffield, UK.

Blaxter, J.H.S. 2000. The enhancement of marine fish stocks. Adv. Marine boil.38, 55 pp.

Brander, K. 1994. (Ed.) Spawning and life history information for North Atlantic cod stocks ICES Cooperative Report No. 205.

Brister, D.J. & Kapuscinski, A.R. 2000. Environmental assessment toll for cage aquaculture in the Great Lakes, version 1.1. Prepard for the Grat Lakes Fishery Commission by the University of Minnesota Institute for social, economic and ecological sustainability. St Paul, Minnesota. (Available in the internet at: http://www.glfc.org/boardcomm/clc/EATq/index.htm).

Bøhle, B. 1974. Temperaturpreferanse hos torsk (*Gadus morhua* L.). Fisken og Havet Ser. B, 20: 1-28.

Dahle, G. 1994. Genetic studies of families of Arcto-Norwegian and Norwegian coastal cod: preliminary random amplified polymorphic deoxyribonucleic acid studies. *ICES Mar. Sci. Symp.* 198, 684-687.

Dahle, G., & Jørstad., K. 1993. Haemoglobin variation in cod – a reliable marker for Arctic cod (*Gadus morhua* L.). *Fish. Res.* 16, 301-311.

FAO. 2003. www.fao.it

Godø, O. R. & Moksness, E. 1987. Growth and maturation of Norwegian coastal cod and Northeast Arctic cod under different conditions. *Fisheries Research* 5, 235–242.

Hansen, T., Karlsen, Ø., Taranger, G.L., Hemre, G-I., Holm, J.C., Kjesbu, O.S. 2001. Growth, gonadal development and spawning time of Atlantic cod (*Gadus morhua*) reared under different photoperiods. *Aquaculture* 203, 51-67.
Hemre, G-I., Taranger, G.L., Hansen, T. 2002. Gonadal development influences nutrient utilization in cod (Gadus morhua). *Aquaculture* 214, 201-209.
Hindar, K., Ryman, N. & Utter, F. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. 48: 945-957.
Huguenin, J.E. 1997. The design, operations and economics of cage culture systems. Aquacultural Engineering, 16: 167-203.
Hunt von Herbing, I. 2001. Development of feeding structures in larval fish with different life histories: winter flounder and Atlantic cod. *J. Fish Biol.* 59, 767-782.
Jamieson, A., & Otterlind, G. 1971. The use of cod blood protein polymorphisms in the Belt Sea, the Sound, and the Baltic Sea. *Rapp. Réun-Cons int. Explor. Mer.* 136: 28-29.
Jobling, M. (1994) *Fish bioenergetics*. Chapman & Hall, London.
Jobling, M. 1988. A review of the physiological and nutritional energetics of cod, *Gadus morhua* L., with particular reference to growth under farmed conditions. Aquaculture, 70: 1-19.
Jonsson, B. och Alanärä, A. 1998. Svensk fiskodlings närsaltsbelastning - faktiska nivåer och framtida utveckling. Vattenbruksinstitutionen, Sveriges Lantbruksuniversitet. Rapport nr 18.
Kapuscinski, A.R. & Brister, D.J. 2001. Genetic impacts of aquaculture. In: Environmental impacts of aquaculture (ed. Black, K.D.). Sheffield Academic Press, Sheffield, UK.
Karlsen, Ø., Holm, J. C. & Kjesbu, O. S. 1995. Effects of periodic starvation on reproductive investment in first-time spawning Atlantic cod (*Gadus morhua* L.). *Aquaculture* 133, 159–170.
Kelly, L.A. & Elberizon, I.R. 2001. Freshwater finfish cage culture. In: Environmental impacts of aquaculture (ed. Black, K.D.). Sheffield Academic Press, Sheffield, UK.
Kvenseth, PG. and Öiestad, V. 1984. Large scale rearing of cod fry on the natural food production in an enclosed pond. Flödevigen Rapportserie 1: 645-655.
Lambert, Y., & Dutil, J-D. 2001. Food intake and growth of adult Atlantic cod (*Gadus morhua* L.) reared under different conditions of stocking density, feeding frequency and size-grading. *Aquaculture* 192, 233-247.
Larsson, P-O. and Pickova, J., 1993. Rearing experiments with Baltic cod, *Gadus morhua* L., for stock enhancement release. Abstract. An International Symposium on Sea Ranching of Cod and other Marine Fish Species, Arendal, Norway, 15-18 June 1993.
Larsson, P-O. and Pickova, J., 1993. Stock enhancement experiments with cod, *Gadus morhua*, in the Bothnian Sea - conditions and expectations. ICES Doc. C.M. 1993/J:18 Sesssion R.
Legget, W.C., Deblois, E. 1994. Recruitment in marine fishes: Is it regulated by starvation and predation in the egg and larval stages? *Neth. J. Sea. Res.* 32: 119-134.
Maitland, P.S. 1986. The potential impact of fish culture on wild stocks of Atlantic salmon in Scotland. In: The status of the Atlantic salmon in Scotland (ed. D. Jenkins & W.M. Shearer), pp. 73-83. ITE Symposium No. 15. Huntingdon, UK.
McNeil W. J. (1991). Expansion of cultured pacific salmon into marine ecosystems. *Aquaculture* **98**, 173-183.
Moksness, E., Støle, R. 1997. Larviculture of marine fish for sea ranching: Is it profitable? *Aquaculture* 155: 341-353.

Morais, S., Bell, J.G., Robertson, D.A., Roy, W.J. & Morris, P.C. 2001. Protein/lipid ratios in extruded diets for Atlantic cod (*Gadus morhua*): effects on growth, feed utilisation, muscle composition and liver histology. Aquaculture, 203: 101-119.

Møller, D. 1966. Genetic differences between cod groups in the Lofoten area. *Nature* 212, 824.

Møller, D. 1968. Genetic diversities in spawning cod along the Norwegian coast. *Hereditas* 60, 1-32.

Nissling, A. and Westin, L. (1997). "Salinity requirements for successful spawning of Baltic and Belt Sea cod and the potential for cod stock interactions in the Baltic Sea." Mar Ecol Prog Ser 152: 261-271.

Olafsen, T. & Dervå, J.M. 2002. Muligheter og risiko ved oppdrett av torsk. En vurdering av økonomiske forhold. Value Sim, www.valuesim.no

Olsen, Y. 1997. Larval rearing technology of marine species in Norway. *Hydrobiologia* 358, *27-36.*

Otterlei, E., Nyhammer, G., Folkvord, A. & Stefansson, S.O. 1999. Temperature- and size-depebdent growth of larval and early juvenile Atlantic cod (*Gadus morhua* L.): a comparatory study of Norweigian coastal cod and northeast Arctic cod. Can. J. Fish. Aquat. Sci. 56: 2099-2111.

Pedersen, T., & Jobling, M. 1989. Growth rates of large, sexually mature cod, *Gadus morhua,* in relation to condition and temperature during an annual cycle. *Aquaculture* 81, 161-168.

Pickova J., Dutta, P.C., Larsson, P-O., Kiessling, A. 1997. Early embryonic cleavage pattern, hatching success and egg-lipid fatty acid composition: Comparison of cod stocks. Can. J. of Fish. Aquat. Sci. 54(10): 2410-2416.

Pickova, J. & P.-O. Larsson. 2003. Rearing and release experiment with Baltic cod. Aquaculture Research, 34: 1231-1233.

Pickova, J. and Larsson, P-O., 1992. Rearing experiments with cod. Comparison between Baltic cod and Skagerrak coastal cod. ICES Doc. C.M. 1992/F:12.

Pillay, T.V.R. 1992. Aquaculture and the environment. Fishing News Books, Oxford, UK.

Purchase, C.F., & Brown, J.A. 2001. Stock-specific changes in growth rates, food conversion efficiencies, and energy allocation in response to temperature change in juvenile Atlantic cod. *J. Fish. Biol.* 58, 36-52.

Rosenlund, G. 1998. Enæringsbehov hos stamfisk - betydning for produksjonen av egg og yngel. Norsk *Fiskeoppdrett* June, 1998.

Rosenlund, G. 2002. Stamfiskförets betydning for produksjonen av egg og yngel. Norsk *Fiskeoppdrett* 18, 40-43.

Ruzzante, D.E., Taggart, C.T. & Cook, D. 1999. A review of the evidence for genetic stock structure of cod (*Gadus morhua* L.) populations in the NW Atlantic and populations affinities of larval cod off Newfoundland and the Gulf of St. Lawrence. Fisheries Research, 43: 79-97.

Sick, K. 1965. Haemoglobin polymorphism of cod in the Baltic and Danish Belt Sea. *Hereditas* 54(1), 19-48.

Solemdal, P., Dahl, E., Danielssen, D.S., Moksness, E. 1984. The cod hatchery in Flødevigen – background and realities. In Moksness, E., Støle, R. 1997. Larviculture of marine fish for sea ranching: Is it profitable? *Aquaculture* 155, 341-353.

Swedish Environmental Protection Agency (Naturvårdsverket). 1999. Bedömningsgrunder för miljökvalitet, Kust och hav. Rapport nr. 4914.

Svedäng, H.,Öresland, V., Cardinale,M. Hallbäck, H, Jakobsson, P. 2002. Finfo 2002:6, Fiskeriverket informerar. De kustnära fiskbeståndens utveckling och nuvarande status vid svenska västkusten

Svåsand, T., Jørstad, K.E., Otterå, H., & Kjesbu, O.S. 1996. Differences in growth performance between Arcto-Norwegian and Norwegian coastal cod reared under identical conditions. *J. Fish. Biol.* 49, 108-119.
Svåsand, T., Kristiansen, T.S., Pedersen, T., Salvanes, A.G.V., Engelsen, R. & Nordtvedt, M. 1998. Havbeite med torsk – artsrapport. Norges forskningsråd, 78 pp. In Norwegian.
Svåsand, T; Kristiansen, TS; Pedersen, T; Salvanes, AGV; Engelsen, R; Naevdal, G; Nordtvedt, M. 2000. The enhancement of cod stocks. Fish and Fisheries. Vol. 1, no. 2, pp. 173-205.
Utter, F., Hindar, K. & Ryman, N. 1993. Genetic effects of aquaculture on natural salmonid populations. In Salmon Aquaculture (ed. By K. Heen, R.L. Monahan & F. Utter), pp. 144-165. Fishing New Books, Oxford.
Walden, J. 2000. The Atlantic cod: The potential for farming in Shetland. *Fisheries Information Note,* No. 3. North Atlantic Fisheries College. Shetland Fisheries Training Centre Trust.
Van der Meeren, T. 1993. Feeding, ecology, nutrition and growth in young cod (*Gadus morhua* L.) Larvae. Dr. Scient Thesis. Dept of Fisheries and Marine Biology. University of Bergen.
Villanueva, B., Woolliams, J. A. And Gjerde, B. 1996. Optimum designs for breeding programmes under mass selection with an application in fish breeding. Animal Science 63: 563-576.
Willoughby, S. 1999. Manual of salmonid farming. Fishing News Books, Oxford, UK.
Volpe, J.P., Glickman, B.W. & Anholt, B.R. 2001. Reproduction of aquaculture Atlantic salmon in a controlled stream channel on Vancouver Island, British Columbia. Trans. Am. Fish. Soc., 130: 489-494.
Youngson, A.F., Dosdat, A., Saroglia, M. & Jordan, W.C. 2001. Genetic interactions between marine finfish in European aquaculture and wild conspecifics. J. App. Ichthyology.

Supplement/Bilaga 1

Yttrande till Fiskeriverket

FISKAVDELNINGEN
Anders Hellström

2003-04-04 Dnr 2003/256

Smittskyddsaspekter på torskodling

35-973-03

Statens Veterinärmedicinska Anstalt (SVA) har beretts möjlighet att inkomma med synpunkter i ovan nämnda fråga.

Nordisk fiskodlingsverksamhet har under många års tid varit inriktat på uppfödning av laxfiskar. Den erfarenhet och kompetens man har vad gäller torsk är därför begränsad till ett fåtal undersökningar på vildlevande torsk samt de erfarenheter man de senaste åren erhållit genom norska försök att odla arten.

De sjukdomar som vi vet kan ha betydelse för torsk är följande: Viral Haemorrhagisk Septikemi/VHS, Infektiös pankreasnekros (IPN), Viral Erythrocytisk Nekros (VEN/Piscine Erythrocytic Necrosis (PEN) . Vibrio salmonicida, Cod ulcus-syndrom (CUS), Gyrodactylus spp.

- VHS -förekommer i två former marin och klassisk. Sverige har godkänts som sjukdomsfri zon för sjukdomen med undantag för ett område med 20 km radie och centrum i Björkö på den svenska västkusten. Den marina typen av viruset har påvisats på regnbågslax (Onchorhynchus mykiss) i odling belägen i Göteborgs skärgård samt förekommer endemiskt i odlingar belägna i den åländska skärgården samt i finska viken. Viruset har också påvisats ett flertal gånger på såväl torsk som skarpsill (*Sprattus sprattus*) och strömming/sill (*Clupea harengus*) i Kattegatt/Skagerack och i södra Östersjön.
- IPN förekommer i ett flertal serotyper varav typen ab och sp anses sjukdomsorsakande hos laxfisk. Jag har sett uppgifter på att IPN i försök har kunnat överföras till torsk och ge sjukdom och dödlighet. I vildlevande bestånd är sjukdomen ej påvisad. Det kan ej uteslutas att vildfångad torsk kan vara bärare av viruset.
- Viral Nervös Nekros (VNN/Viral Encephalopati och Retinopati (VER) orsakas av ett virus ur familjen Nodaviridae. Viruset anses kunna orsaka sjukdom på fiskarter tillhörande ordningarna Scorpaeniformes, Perciformes, Pleuronectiformes, Tetraodontiformes samt Gadiformes. Sjukdomen förekommer i Asien och flera europeiska länder medan vårt närområde anses som fritt från sjukdomen. Smittspridning sker mellan fiskar via kontakt eller via vattnet, det är också troligt att viruset kan överföras från moderfisk till rom. Att torsk anses som mottaglig för sjukdomen kan hänföras till ett sjukdomsutbrott på ungtorsk i Nova Scotia 1999. Någon verksam terapi mot sjukdomen finns inte.
- Viral Erythrocytisk Nekros (VEN/Piscine Erythrocytic Necrosis (PEN)). Orsakas av ett iridovirus. Viruset orsakar sjukdom på lax, sill och torsk mfl. fiskarter. Sjukdomen är påvisad i fisk från Atlanten, Stilla havet och Medelhavet. Vad vi vet är viruset ej känt från vårt närområde. VEN uppges kunna orsaka massdödlighet på sill men endast låg kronisk dödlighet på andra arter. Viruset kan överföras från fisk till fisk och från föräldradjur direkt till rommen (vertikalt). Någon verksam terapi mot sjukdomen finns inte.

- Vibrio salmonicida –kallvattenvibrios – Hitrasjuka. Bakterien är fram för allt känd för att orsaka sjukdom på lax i odling i Nordatlanten. Det är påvisat att bakterien kan överföras från lax till torsk och vica versa. Hos torsk anses inte sjukdomen ha ett lika allvarligt förlopp som hos lax.
- Cod ulcus-syndrom (CUS) förekommer på 1-2 årig torsk i området mellan Norge, Sverige och Danmark. Visar sig som sår på fiskens sidor som så småningom övergår i ärrvävnad. Vanligast förekommande under sommar och tidig höst. Två virus, ett irido- och ett rhabdo virus har isolerats från sjuk fisk. Denna sjukdom är så vitt man vet ej möjlig att överföra till laxfiskar.
- Furunkulos (ASS) (Aeromonas salmonicida salmonicida)
  har vid enstaka tillfällen påvisats på torsk och vid ett tillfälle (Canada) gett upphov till sjukdom. Fältstudier talar dock för att torsk är relativt okänslig för smittämnet.
- Gyrodactylus spp, de arter som här är aktuella är inte patogena för laxfiskar.

Av ovan nämna sjukdomar är IPN, VEN och eventuellt VNN vertikalt överförbara, dvs från föräldradjur direkt till avkomman. Ingen av dessa bedöms dock som någon uttalad riskfaktor under förutsättning att odlingarna använder sig av lokala bestånd från vattenområdet i odlingens närhet.

Sammanfattning

Det är troligt att vi med ett ökande antal torskodlingar kommer att påvisa fler infektiösa smittämnen än vad vi idag känner till från arten. Som i alla vattenbrukssammanhang föreligger risk för sjukdomar som beroende på odlingssituationen (täta grupper) kan ge en högre sjuklighet i en odling än vad samma sjukdom skulle ge i vildlevande bestånd. Påverkan på, respektive av, vildlevande bestånd är desamma som för laxfiskar. Som anges ovan finns det också sjukdomar som är överförbara mellan torsk och laxfiskar och vice versa. En frågeställning som SVA inte har kompetens för är huruvida spridningen av olika underarter av torsk kan få konsekvenser för vildlevande bestånd. Ur smittskyddssynpunkt bör samma krav ställas på en torskodling som en odling innehållande laxfiskar. Ett undantag är dock att sättfiskodling för torskfisk måste tillåtas vara belägen i kustzon till skillnad från förfarandet för övriga odlade fiskarter. I en sådan odling avsedd för torskyngel för utplantering eller vidareodling i annan anläggning, rekommenderas tills vidare karantänsliknande drift samt ett förfarande likvärdigt det som används för rekrytering av laxfisk inom kompensationsodlingsverksamheten för att förhindra spridning av infektiösa sjukdomar. I de fall gonadprodukter från torsk importeras föreligger, precis som för laxfiskar, en risk för införande av sjukdomar som vi inte har i Sverige.

I utarbetandet av detta yttrande har förutom generaldirektören deltagit chefen för SVAs fiskavdelning statsveterinär Anders Hellström, föredragande.

L E Edqvist
Generaldirektör

Anders Hellström
Statsveterinär