

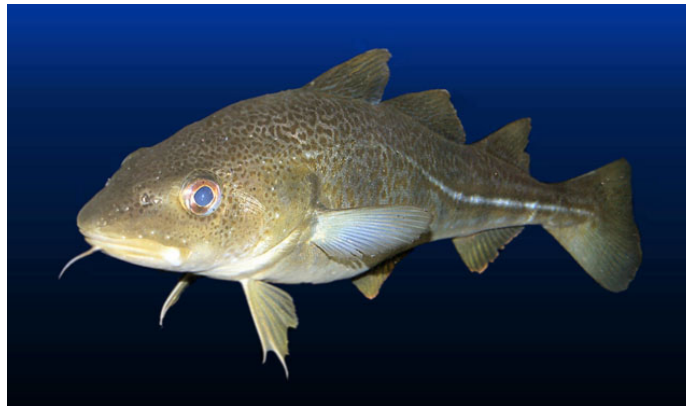


GENIMPACT

Evaluation of genetic impact of aquaculture
activities on native populations.
A European network

WP1. Genetics of domestication, breeding and
enhancement of performance of fish and shellfish

Atlantic cod - *Gadus morhua*



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Joerstad K.E., Fjalestad K.T., Ágústsson T. and Marteinsdottir G. (2006). Atlantic cod – *Gadus morhua*. In: “Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations.” D. Crosetti, S. Lapègue, I. Olesen, T. Svaasand (eds). GENIMPACT project: Evaluation of genetic impact of aquaculture activities on native populations. A European network. WP1 workshop “Genetics of domestication, breeding and enhancement of performance of fish and shellfish”, Viterbo, Italy, 12-17th June, 2006,1-6 <http://genimpact.imr.no/>

A. Biology, ecology and genetics

Distribution and capture

Cod inhabit the continental shelves and banks in most areas in the North Atlantic (1) and are therefore distributed in many different environments with respect to temperature and salinity (Fig. 1). A comprehensive overview of biological characters for each population can be found in International Council for Exploration of Sea (2).

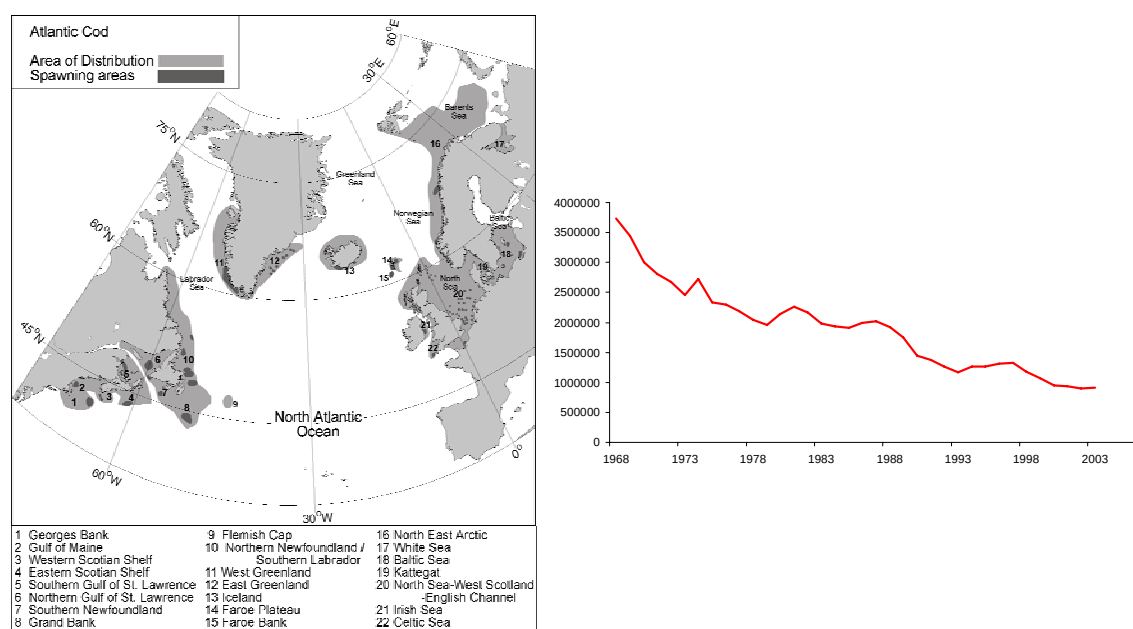


Fig. 1. Distribution and spawning areas of all major cod stocks and total catch (tonnes) of cod in the N. Atlantic (3,4).

Capture

Abundance of cod varies greatly among the different areas of the North Atlantic. Most of the cod stocks have been exposed to high fishing mortality. In 1970, the total catch was about 3.5 million tonnes in North Atlantic (Fig. 1). Today the total catch has declined to less than a million tonnes, mostly because of depletion of stocks and that some stocks have collapsed (3).

Biology

The cod has a long historical record as an important marine resource throughout the distribution range. It is a bottom fish species mainly distributed from the shoreline and down to the continental shelf. Spawning normally occurs in winter / spring on well known spawning

sites (2). Mature cod migrate to the spawning sites where they aggregate and spawn. It is a very fecund species with numbers of eggs ranging from thousands to 20-30 millions per female (5). During each season the females spawn several batches of eggs, which are fertilised externally. The eggs are pelagic, and egg buoyancy and the hydrographical conditions are important factors for determining the geographical distribution (4, 6). Cod larvae are also pelagic and they first feed on plankton (copepod larvae), then krill and other small crustaceans. At larger size, cod mainly feed on fish. During summer or autumn the fry change their pelagic distribution and settle to the bottom.

There are large variation between different populations with regard to larval distribution and migration back to spawning sites. Most extreme is the Northeast Arctic cod population, which has the main spawning sites located near the Lofoten Island on the Norwegian coast. The eggs and larvae drift north with the coastal current and are distributed over a large area in the Barents Sea - Spitsbergen. In connection with spawning, the cod has to migrate from the Barents Sea and back to the spawning sites around Lofoten, which involve large distances (2).

Population genetics

The relationship between stationary and migratory cod populations was first discussed in detail more than 100 years ago (7). First genetic studies were initiated during the 1960s. Haemoglobin was the first genetic marker that was used to study cod populations (8), and large differences in allele frequencies were found in more detailed studies (9, 10). The haemoglobin results and other studies on blood proteins (11) supported the view that cod could be divided into migratory arctic cod, and more stationary coastal cod. However, it has been suggested the variation in allele frequency of haemoglobin along the Norwegian coast could also be explained by selection due to different environmental conditions (10). Studies employing allozyme markers have shown relatively limited variation among cod populations along the Norwegian coast (12, 13).

More recent studies employing various DNA markers have yielded results ranging from panmixia or high gene flow (mtDNA) across much of the Atlantic (14, 15) to the presence of significant population structuring (microsatellite DNA, scnDNA) on small to medium spatial scales (16, 17, 18). Similar results have been reported from the western Atlantic, where temporally stable differences between inshore and offshore cod off Newfoundland have been demonstrated (19). The gene marker *Pan* I exhibits particularly large differences in allele frequencies between samples collected in the Barents Sea and in coastal areas of Norway. While samples of Northeast Arctic cod are almost fixed for the *Pan* I^B allele, samples of coastal cod exhibit high frequencies of the *Pan* I^A allele (17, 18). The large genetic variation between cod from different areas, even at a minor geographic scale suggests that many cod populations could be adapted to local environmental conditions (20).

B. Breeding and culture practices

Production

Atlantic cod farming is predicted to become the second most economically important marine finfish species, after Atlantic salmon, to be farmed in Europe. Present global production figures are shown in Tab. 1 (21) and the preliminary results for 2005 are 7,000 tonnes. This is relatively low. However, confident industry analysis predicts annual harvests of 175,000 tonnes by 2010 (22).

	2000	2001	2002	2003	2004
Norway	169	864	1,253	2,185	3,168
Iceland	<0.5	140	192	380	636
UK		15			8
<i>Total</i>	<i>169.5</i>	<i>1,019</i>	<i>1,445</i>	<i>2,565</i>	<i>3,812</i>

Tab. 1. Atlantic cod aquaculture production (tonnes)

Hatchery practices

Broodstock for farming come from different geographic areas and most hatcheries in Norway have mixtures of north east arctic cod and coastal cod. Cod spawn easily in captivity, and due to the high fecundity, large amounts of high quality eggs and larvae can be produced. When cod are held in intensive culture conditions they mature within 2 years from hatching (23), much earlier than their wild counterparts (24). Such “early” maturation has significant impacts on potential production profitability as maturation reduces growth potential. Thus, it extends the production cycle (by a minimum of 6 months) and has negative impacts on the product quality. Cod eggs are usually incubated at 5-7° C and hatch after 15-20 days. Larvae start feeding 4-5 days after hatching.

Extensive and semi-extensive methods for larvae production rely on natural plankton for start feeding. Most hatcheries today have an intensive production which includes live food production, feeding larvae with rotifers and artemia (25).

Grow-out

There are two main methods of cod farming in Iceland and Norway: one is capturing and on-growing of wild cod, the other is production of cod from hatching to market size. The grow out is taken place in net pens in the sea.

The number of escaped cod in Norway for 2003 and 2004 was 75,000 individuals and the estimate for 2005 is approx 167,000 individuals. It is suggested that the cod may be able to make holes in the net. The Norwegian Research Council is financing a project called “Why and how does cod escape?”, which includes behaviour studies both under experimental and commercial farming conditions. The goal is to use this information to suggest methods for surveillance, recapture of escaped fish and to predict possible interactions.

Selective breeding

As intensive farming of cod has had renewed interest the last years, selective breeding programmes have been initiated both in Norway and Iceland. The Norwegian Institute of Fisheries and Aquaculture Research has the responsibility for the national breeding programme financed by the Ministry of Fisheries and Coastal affairs. MarineBreed, a commercial company, has also started a breeding programme. In Iceland the breeding programme for cod has resulted in a company (Icecod) owned by both governmental institutes and private companies (26). A programme called “Atlantic Cod Genomics and Broodstock Development” was started in Canada in 2005 (27). The aim of the programme is to develop tools to identify cod with superior traits of commercial importance. Base populations in the Norwegian programmes have been produced from both North East Arctic cod and coastal populations. Testing and breeding strategies follows very much breeding programmes for

Atlantic salmon. The three European breeding programmes have carried out one round of selection based primarily on growth rate but also to some extent included disease resistance, early maturation and quality traits. A combined family and individual selection is used. The test fish in the breeding programmes are farmed in different environments (geographically) and the results will provide an indication of possible genotype-environment interactions.

Recent quantitative genetic studies (28-31) have shown that estimates of heritability for production traits (e.g. growth) are of magnitude as for many other fish species. Tests for parental assignment have been developed based on microsatellite markers (32), and the breeding programme in Iceland is using genotyping instead of separate rearing of families. Studies on possible QTLs for disease resistance and quality traits are ongoing and could be included in breeding programmes by Marker-Assisted-Selection.

C. Interaction studies

The development of cod aquaculture has raised questions about possible environmental effects of cod farming, including possible genetic influence of farmed populations on wild populations. Farmed cod could be bred with a genetic marker that would positively distinguish an escapee from a wild individual. This gives a unique possibility for tracing the effects of escape and in-cage spawning on wild populations. Genetic marker for cod was developed at the Institute of Marine Research in the 1980s (33), and a new cod broodstock with the same gene marker is now under development.

Much research is going on to prevent early maturation. This is important both for aquaculture and for possible gene interactions between farmed and wild fish. The Institute of Marine Research in Norway started 2006 a study about the effects of spawning in net pens.

Prevention of escape must be achieved through technical changes adapted surveillance and increased knowledge about cod's behaviour in cages. The Directorate of Fisheries, Norway, has initiated in the spring 2006 a plan to reduce escapees from aquaculture. One out of 29 proposed actions is the consideration of using sterile fish in aquaculture.

D. Conclusions / Implications

Cod is one of the most important marine resources in the north Atlantic and consists of a number of populations, in some cases even within a minor geographic range. Several of these are depleted, and with respect to small populations such as the Norwegian coastal cod, these are possibly more vulnerable to human impacts including aquaculture.

The interest in cod farming is increasing in several countries, and similar environmental problems are expected as have been experienced in the salmon farming industry. Cod breeding programmes have already been initiated in Norway and Iceland.

Studies on the possible gene interactions between wild and farmed or ranched cod have already started (33, 34), and as much knowledge as possible are required to be prepared for the expected increase in cod farming. More information about the small local populations such as coastal cod in Norway is required, especially to study the potential for local adaptation (35). In this regard it is urgent to conduct "common garden" experiments to evaluate population specific life history characteristics which are relevant for local adaptation.

Norway has a law regulating all aspects of aquaculture, and escapes from farming have to be reported to the Directorate of Fisheries immediately. In serious cases it can also be reported to the police. Research to reduce escapees should be given high priority. Since cod also spawn in net pens the possibility of sterile fish will be investigated. The goal for a breeding

programme (and farming/management in general) should be cod reaching harvest size before maturation. Studies on genetic variation for age at sexual maturation should be prioritised to include this in the breeding criteria (in addition to other ways of reducing the problem of early maturation).

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