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Possibilities and limitations of extensive aquaculture of marine fish - evaluation of current results with Atlantic cod and further prospects

by

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ABSTRACT
We discuss the possibilities and limitations of extensive aquaculture of marine fish based on the results from a programme that has evaluated the enhancement of local coastal cod (*Gadus morhua* L.) stocks in Norway. The cod enhancement programme has investigated the effects on ecosystems of releases of large numbers of cod juveniles, the carrying and production capacity for cod, and mortality, migration, feeding and growth of released and wild cod. The importance of different management, ecosystem and species characteristics for the outcome of enhancement experiments is evaluated. Suggestions are made for future investigations of enhancement potential of marine fish stocks in Norway and other areas, both with regard to experimental logistics and choice of species.

Keywords; carrying capacity, cod, enhancement, ecosystem effects

CONTENTS

Introduction

This introduction offers a short historic review of the background for the investigations on the enhancement of marine fish stocks in Norway, with special emphasis on the research conducted on Atlantic cod (*Gadus morhua* L.) during 1985-1997. In this period important hypotheses were put forward and tested during the "Cod in Fjords Programme" (1985-1990) and the "Norwegian Sea Ranching Programme (PUSH)" (1990-1997).

Cod yolk-sac larvae releases

The idea that man could help nature by filling the sea with small cod to enhance natural cod stocks has persisted since Georg O. Sars discovered the pelagic cod egg and described the early life history of cod in the 1860s (Sars 1879). Sars' report put forward the question of whether nature could be assisted in such a way as to prevent the occurrence of unfavourable years in the fisheries by artificial hatching of fish (*op cit.*). The first Norwegian attempts to enhance local cod stocks by releasing small, newly hatched yolk-sac larvae from the natural spawning of a captive broodstock were initiated in the early 1880s. A hatchery was built at Flødevigen, near Arendal in southern Norway. Production there started in 1884; while parallel activities were initiated in the USA and Canada (Shelbourne 1964; Solemdal *et al.* 1984). Releases of artificially hatched yolk-sac larvae of Atlantic cod continued for nearly a century and were terminated in 1952 in USA and in 1971 in Norway (Solemdal *et al.* 1984).

The rationale for the yolk-sac releases was the simple hypothesis that year-class strength is directly proportional to egg production by the spawning stock (Shelbourne 1964). G.O. Sars had already noticed that many of the eggs were destroyed by wind and waves, and a logical further step was to protect the delicate embryonic stage in a hatchery. Thus, the releases of yolk-sac larvae were believed to significantly increase the year-classes recruited to the fishery while the cod stocks were assumed to be decreasing (Solemdal *et al.* 1984).

During the early part of this century, scientists discovered that variability in the size of fish stocks was largely due to variations in year-class size generated during the first year of life (Hjort 1914, 1926). Johan Hjort raised the hypothesis that there might be a critical period of high and variable mortality when the larvae had to start exogenous feeding, during which differences in year-class sizes are generated. Hjort questioned the practical value of the yolk-sac larvae releases, but his arguments did not gain enough support to change the policy. The Flødevigen hatchery continued yolk-sac releases until 1971 (Solemdal *et al.* 1984), when Tveite (1971), comparing recruitment time-series in enhanced and unenhanced areas, found no statistically significant effects of the yolk-sac larvae releases.

In response to early scepticism about the survival potential of artificially hatched yolk-sac larvae, yolk-sac larvae were released into a large sea water reservoir at the Flødevigen Hatchery (Rognerud 1887). This study showed that larvae could be reared to the juvenile stage in a large enclosure in which they fed on natural zooplankton produced in the seawater during the spring bloom. Dannevig (1889) proposed future releases in which juveniles would be reared to at least one-inch body length before being released into the sea. Hjort and Dahl (1900) also proposed further scientific releases of larger cod (10 cm).

Rollefsen's flatfish experiments
The lack of efficient tagging methods was a main hindrance to measuring the effects of mass releases of yolk-sac larvae. Rollefsen (1940) tried to overcome this problem by using hybrid offspring.

Rollefsen explicitly spelt out the earlier implicit assumption of the yolk-sac larvae releases: for yolk-sac larvae to enhance fish populations, there would have to be a very high mortality rate during the egg- and larval yolk-sac stage in the sea, followed by lower mortality rate during later life stages (Rollefsen 1940). To investigate the fate of released plaice (*Pleuronectes platessa*) and their possible enhancement effect, the released larvae had to be marked so that they could be distinguished from their wild conspecifics. As hybrids of plaice and flounder (*Platichthys flesus*) had not been recorded in Norway, hybridity itself could be used as a natural tagging method (*op cit.*). In 1935-39, therefore Rollefsen released yolk-sac larvae hybrids from crossings of female plaice and male flounder into the Borgenfjord near Trondheim, and afterwards found that a considerable proportion of the metamorphosed flatfish in a part of the fjord consisted of hybrids of plaice and flounder. To compare the viability of the hybrids with that of the parental species, he reared larvae of plaice, flounder, and their hybrids together to the juvenile stage in a sea-water pond, feeding them on natural zooplankton. Under these conditions, the hybrids had far higher survival rates than plaice, but lower than flounder (*op cit.*). Therefore, using hybridity as a natural marker on released yolk-sac larvae might give biased results that would not yield adequate information on the survival potential of released yolk-sac larvae of either of the parent species. The lesson to learn from these experiments is that efficient marking techniques are a prerequisite for efficient testing of the performance and yield of released cod juveniles.

Cod juvenile releases
In the course of this century, more and more evidence has emerged indicating that the mortality rates of fish larvae and juveniles in their natural environment decline rapidly with increasing size (Peterson and Wroblewski 1984, McGurk 1986, Anderson 1988, Sundby *et al.* 1989, Tsukamoto *et al.* 1989, Legget and Deblois 1994, Kristiansen *et al.* 1997). Most mortality rates during the egg, yolk-sac and early post-yolk-sac larval stages are in the range of 5-30 % day^{-1}. By releasing genetically marked yolk-sac larvae Kristiansen *et al.* (1997) was able to show that less than 1 % of the larvae were alive one month after relase, and less than 1 of 150 000 survived one year later. The results of releasing yolk-sac larvae, therefore, seem to be negligable. After metamorphosis, mortality rates of 1-4 % are common during the early juvenile period (Sundby *et al.* 1989, Tsukamoto *et al.* 1989).

When releases of small cod were resumed in the 1970s, large numbers of juveniles could be reared after 1983, and therefore juveniles were released (Øiestad *et al.* 1976, Moksness and Øiestad 1984), in accordance with Dannevig's suggestion (Dannevig 1889). Reared cod juveniles were first released in Flødevigen in 1976 and 1977, when about 1,100 individuals were released (Moksness and Øiestad 1984). The juveniles were released when they were large enough to be tagged by individually numbered tags (> 8 cm in length) so that rates of recapture and yield per released cod could be recorded (*op cit.*). The results of this first cod juvenile release study were presented at the Flødevigen symposium on "The Propagation of Cod *Gadus morhua* L." in 1983. Many scientists expressed interest in performing release experiments with the purpose of testing the hypothesis that local cod stocks could be enhanced by releasing large numbers of reared juveniles (Blaxter 1984, Ulltang 1984).

Originating from the juvenile production experiments at Austevoll (Øiestad *et al.* 1985), about 40,0000 cod juvenile cod were released during 1983-1986 in south-western Norway (Kristiansen and Svåsand 1990, Svåsand and Kristiansen 1990a, 1990b, Svåsand *et al.* 1990). The results of these release experiments were promising with respect to recapture rates and performance of the released fish in the wild, but there was a definite need to lower the cost per juvenile produced and to decrease the fishing mortality of young cod to better exploit the growth potential of released juveniles (Sandberg and Oen 1993).

Cod enhancement investigations 1985-1997 - "Cod in fjords" and the "Norwegian Sea Ranching Program (PUSH)"

Based on the promising results from the releases in the Austevoll region in south-western Norway, a research programme "Cod in fjords" under the Norwegian Fisheries Research Council commenced in 1985 with the Institute of Marine Research, University of Bergen and the Norwegian College of Fishery Science, University of Tromsø as contributors (Svåsand in press). As part of the "Cod in Fjords" programme, cod juveniles were released in Masfjorden in western Norway (Smedstad *et al.* 1994), and along the southern coastline of Norway starting in 1985 (Danielssen and Gjøsæter 1994), and in Troms County, northern Norway starting in 1987 (Kanapathippillai *et al.* 1994). This effort of scaling up the release studies aimed to identify the factors that influence the yield of released cod juveniles in different parts of Norway and to determine whether releases of juvenile cod could even out the natural fluctuations in recruitment in cod stock and thereby stabilise the fishery (*op cit.*).

In principle, the biomass of a cod population may be regulated to stay within its environment's carrying capacity by changes in individual growth rate, mortality rate, the recruitment of small cod, or the fishing mortality imposed by man. Investigations of how these parameters change over time and between release areas may thus yield answers as to whether the supply of reared cod recuits will increase cod production and catches.

In 1990 "Cod in fjords" was expanded into a national program, the "Norwegian Sea Ranching Program (PUSH)", that aimed to identify the biological, ecological, legal and financial prerequisites for sea-ranching cod, Atlantic salmon (*Salmo salar*), Arctic char (*Salvelinus alpinus*) and European lobster (*Homarus gamarus*) (Svåsand in press, Svåsand *et al.* 1988).

The PUSH programme had the following aims (Svåsand *et al.* 1998):

- Optimise and further develop methods for production of cod juveniles
- Investigate the relationship between size at release and mortality from release to recapture of cod juveniles
- Investigate the causes of natural mortality of released cod juveniles, including predation from birds
- Estimate tag loss rates
- Investigate how the release strategy could be optimised
- Investigate migration, survival, individual growth and recapture percentage of cod juveniles released in different coastal and fjord areas
- Investigate geographical variability in individual growth and recapture rates, both along the coast (in the north-south direction), and across the coastal line from the inner fjord areas out towards the open exposed coast.

- Investigate how different exploitation regimes and recapture strategies influence catches of released cod juveniles
- Investigate, by means of matemathical modelling, how carrying capacity varies in different areas

Production, tagging and releases of cod juveniles

Between 1990 and 1994, a total of nine projects were involved in the production of cod juveniles either in seawater enclosures (ponds), basins, plastic bags in seawater enclosures, plastic bags in the sea, or in small indoor tanks (Svåsand *et al.* 1998). A total of 1.37 million cod juveniles with mean body weights ranging 5 to 10 g were produced during 1990-1994 (Table 1).

Table 1. Production of cod fry (about 10 g wet weight) for stock enhancement and net pen rearing in 1986-1989 and 1990-1994 (PUSH) using various methods of production (Anon. 1995).

	Production (x 1000)	
Production method	1986-1989	1990-1994
Seawater enclosures	1088	914
Basin	8	122
Plastic bags in seawater enclosures		195
Plastic bags in the sea	175	128
Intensive production		11
Total	1271	1370

Despite some between-year variability in production, sufficient numbers of juveniles of acceptable quality were produced in order to perform releases in several fjord and coastal regions (Fig. 1). From 1990 to 1995, a total of 720 000 tagged cod juveniles were released at Øygarden, Masfjorden and Austevoll in western Norway, Ytre Namdal in mid-Norway, in the area of Vestfjorden in northern Norway, and in Malangen (Stålvikbotn) and Ullsfjord/Sørfjord in northern Norway (Fig. 1, Appendix 1).

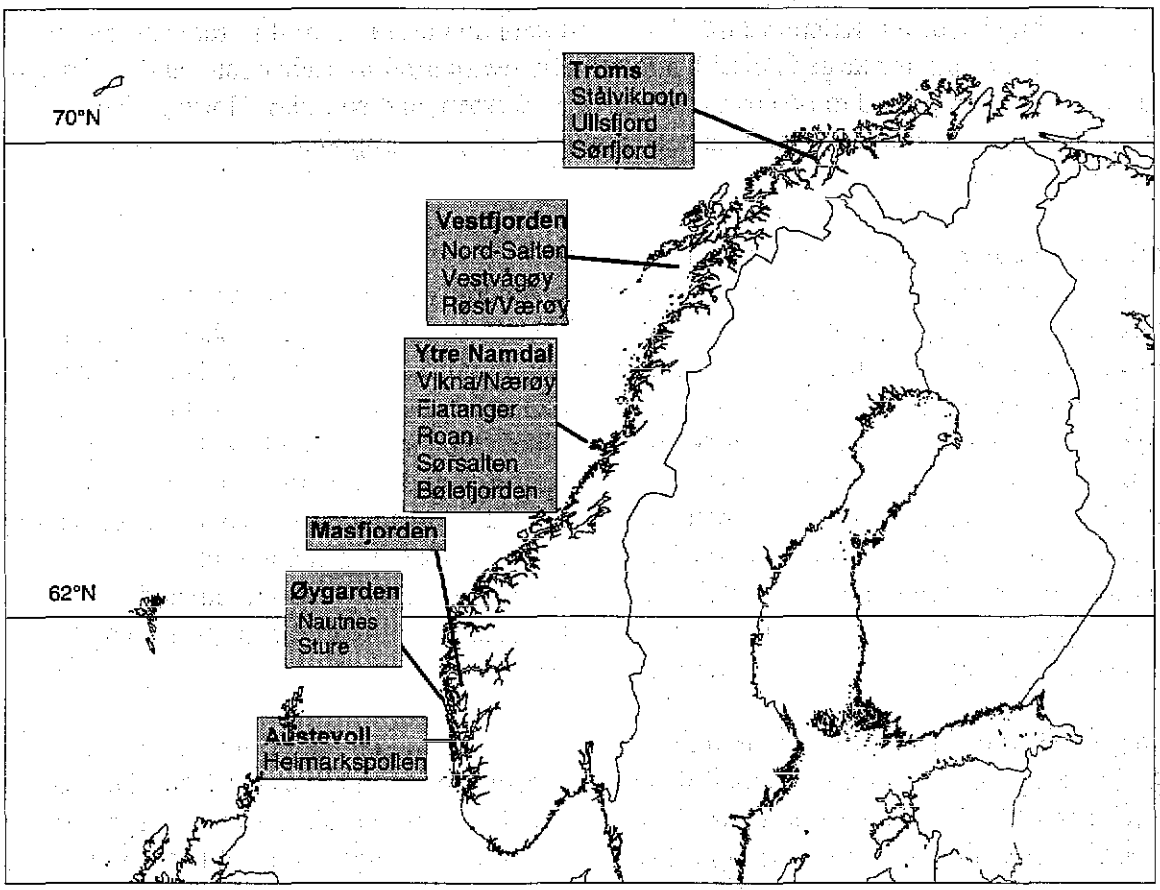

Figure 1. The main release areas (including sub-areas) for artificially reared cod during the Norwegian Sea Ranching Programme (PUSH) (Svåsand *et al.*, 1998). Details of the release areas are given in Appendix 1. Reared cod were also tagged and released on the Norwegian Skagerrak coast in 1977-89.

The broodstock consisted exclusively of cod caught in the region in which the offspring were intended to be released. Genetic studies were incorporated into release experiments in Masfjorden, Øygarden and Vestfjorden. Except for cod tagged with a genetic marker, very few differences were observed between wild and reared cod in genotype distributions and gene frequencies, indicating that genetic selection and genetic drift were a minor problem (Svåsand *et al.*, 1998).

Efficient methods of tagging and marking cod juveniles were developed, and included external tags (anchor tags), chemical tags such as alizarin complexone and oxytetracycline (Pedersen and Carlsen 1991, Nordeide *et al.* 1992, Blom *et al.* 1994), and genetic markers (Jørstad *et al.* 1990, Kristiansen *et al.* 1997, Jørstad *et al.* 1994). All the cod juveniles released for sea-ranching purposes were tagged.

Investigations of tag loss when marking juvenile cod by external anchor tags revealed that tag loss rate was dependent on tag type, with a mean tag loss of about 10 % during the first year after tagging (Otterå *et al.* 1998). The question of whether cod juveniles tagged with external tags are more susceptible to predation has been addressed by comparing recapture rates from cod tagged with external or internal tags. The results reveal that there is no tendency towards higher predation on cod juveniles tagged with external tags, neither from fish predators (Svåsand *et al.* 1987, Otterå *et al.* 1998), nor from cormorants *(Phalacrocorax carbo carbo)* (Otterå *et al.* 1998). It is difficult to estimate the proportion of tags recaptured by fishermen that are actually reported. Kristiansen (1996) used data on natural mortality rate and recapture distribution over time for large cod with a relatively low natural mortality rate, and estimated the proportion tag reported to be around 40-65 % in western and southern Norway. The proportion of tags reported probably depends on fish size, geographical area and tag density in the cod population.

Migration and adaptation to the wild environment

Released coastal cod, both cultured and wild, were generally recaptured close to the release/tagging site (Svåsand and Kristiansen 1990a, Kristiansen in press, Otterå *et al.* in press b, Skreslet *et al.* in press, Nøstvik and Pedersen in press, Svåsand *et al.* 1998). More than 50 % of the released cod were recaptured less than 6 km from the release site (*op cit.*). This is in contrast to the situation for Northeast Atlantic cod stock, which perform long spawning and feeding migrations between the Barents Sea and the Norwegian coast (Bergstad *et al.* 1987). There was a trend towards increased migration distance from south to north along the coast, and the distance increased with increasing body size. In general, cultured cod seemed to disperse more than wild cod, tagged and released in the release area, and dispersion appeared to increase with increasing size at release of reared cod juveniles (Nøstvik and Pedersen in press, Svåsand *et al.* 1998).

Cultured cod adapted well to a life in their natural environment, and after only a few weeks their choice of prey was similar to that of wild cod (Kristiansen and Svåsand 1992, Nordeide and Salvanes 1991, Nordeide and Fosså 1992, Svåsand *et al.* in press). However, during the first period after release, cultured cod probably suffered from a higher mortality than wild cod in the same size range (unpubl. data).

Feeding and trophic position of coastal cod in Norway

A review of feeding studies on cod reveals that despite the substantial variability in the diet of cod along and across the coast, corresponding to variations in abundance of different prey groups, there seem to be some general trends in the diet composition of cod on the Norwegian coast. Benthic invertebrates, especially crustaceans, are important prey for small cod (< 30 cm in length), but slow moving prey such as echinoderms and benthic molluscs are generally unimportant. There is a gradual shift in the diet from small invertebrates to fish as cod grow. Large cod also eat small cod and also other fish that may be competitors for cod.

In southern and western Norway, labrids and gobies are an important part of the cod diet (Kristiansen and Svåsand 1992, Hop *et al.* 1992, 1993, 1994, Salvanes and Nordeide 1993), while these prey groups plays a minor role as food in northern Norway (Kanapathippillai *et al.* 1994). Herring (*Glupea harengus*), capelin (*Mallotus villosus*) and especially euphausiids may be important food species for cod in the fjords in northern Norway north of Vestfjorden (Klemetsen 1982, dos Santos and Falk-Petersen 1989, Kanapathippillai *et al.* 1994). Brachyura/anomura (crabs, hermit crabs and galatheoids) play a very important role as food for medium-sized cod (20-60 cm in length) on the coast south of about 69 °N (*op cit.*), while euphausiids (mainly herbivorous *Thyssanoessa* spp.) are very important prey for medium sized cod in the fjords in Troms (dos Santos and Falk-Petersen 1989, Kanpathippillai *et al.* 1994). These differences indicate that the cod population in the fjords in Troms in northern Norway receive relatively more of the energy through a short pelagic food chain (phytoplankton -> euphausiids ->cod) than at locations further south.

The numbers of species and relative abundance of competitors change from south to north. In the south, on the Skagerrak coast, 0 and 1-group whiting and cod share several prey groups (Hop *et al.* 1994). In the western part of Norway (Masfjorden), small cod, poor-cod (*Trisopterus minutus*), saithe (*Pollachius virens*) and small pollack (*Pollachius pollachius*) all feed on gobiids (Salvanes and Nordeide 1993) which in turn rely mainly on zooplankton (Fosså 1991). In northern Norway, the abundance of whiting, poor-cod, pollack and gobiids decrease northwards along the coast and these species are rare north of Vestfjorden (about 68 ^{o}N). Thus, small cod may compete with many gadoid species in the south (saithe, poor-cod, pollack, whiting and haddock) while saithe seem to be the main gadoid competitor in the north. Furthermore, interspecific competition may be more important in the south, while intraspecific competition may be more important in the north where the density of cod is high and there is low abundance of other gadoids except for saithe.

Cannibalism has been observed in most investigations (see references above), and may be a very important density dependent mortality factor for small cod, especially in the north where fishing mortality is relatively low and the abundance of large cod is higher than in the south (Svåsand *et al.* 1998).

Carrying and production capacity for cod

Ecosystem analyses were performed in the most comprehensively studied release areas, Hordaland and Troms, on the basis of extensive data collection and mathematical ecosystem modelling. Large differences were found in carrying capacity and in the growth and survival of cod in different release areas. As the result of fewer competitors and a more pelagic life style, the largest carrying capacity of cod is attained in the fjords of Troms (Svåsand *et al.* 1998).

Simulations using dynamic ecosystem models have revealed that the supply of zooplankton through advection to the release areas in southern Norway has a large and indirect impact on the production of fish (Aksnes *et al.* 1989, Giske *et al.* 1991, Salvanes *et al.* 1992, 1995). The simulations also showed a strong density-dependent regulation of cod production. Limited and varying carrying capacity means that the areas investigated can not support large year classes or yearly releases of cod (Nordeide *et al.* 1994).

Individual growth and mortality of released and wild cod

Growth

Individual growth was highest in the outer coastal areas (Svåsand *et al.* 1998), and is in accordance with ecosystem model predictions. The results also showed a lower growth rate in the northern fjord areas than in southern areas. Highest growth rate were found in Øygarden. In all areas except Øygarden, reared cod had higher growth rates than wild cod (Nøstvik and Pedersen in press, Otterå *et al.* in press a, Svåsand *et al.* 1998). Differences in growth rates between males and females were also observed (Svåsand *et al.* 1998).

Mortality

The survival of the released fish is the most important success factor in sea ranching with cod. The basic idea of sea ranching is to protect juveniles during the period of very high mortality in the sea. The other aspect is that we want to harvest a (much) larger biomass than we release, so the mortality rate needs to be lower than weight growth rate of the released cohorts.

An ideal area for releases of cod juveniles should have low natural mortality and high growth rate, and the degree of success depends strongly on the values of the growth and mortality parameters.

Mortality is usually divided into fishing mortality and natural mortality, which is defined simply as mortality due to other causes than fishing. Natural mortality is most important when planning a stock enhancement project, since to some extent we can optimise the fishing mortality and sizeselection in the fishery. The natural mortality of pre-recruit cod is seldom known and is also very size- and locality-dependent. Fishing mortality and natural mortality are also linked, since an increase in fishing mortality lowers the numbers of large cod and other potential predatory fish.

After the released fish have recruited to the fishery, the decrease in abundance is indicated by the decrease in numbers of recaptures per year. If this rate of decrease is to be the same as the mortality rate, we must assume that there is no size selection in the fishery and that the effort in the local fishery is the same each year. If selection curves and effort are known these factors may be corrected for, but this is seldom the case in a multi-gear fishery. At what size the cod recruits to the fishery varies from area to area. In western Norway, where the fish are mainly caught by recreational fishermen, the age of 50 % recruitment is at about a length of 30 cm (2-group), but in Troms in northern Norway it may be as late as at the length of about 45 cm (5-group stage).

If the mortality estimates are based on research surveys, we have more control of effort and selectivity, but it may be difficult to obtain large enough samples of tagged fish. However, if we can assume similar mortality rates of reared and wild fish, catch per unit effort (CPUE) data from wild fish can be used to estimate mortality (e.g. Salvanes and Ulltang 1992).

In general, the mortality rate and hence the recapture percentages of released cod juveniles (and wild cod) was highly size dependent in most areas. Releases of 0-group and small 1-group (15-20 cm in length) in Øygarden (Otterå *et al.* in press a), in Troms (Pedersen 1997) and in Ytre Namdal (Kristiansen in press) gave few recaptures (<2.5%, 0.6-2.2 %, and c. 0.1%), respectively. This indicates a large accumulated natural mortality rate during the time period from release of the smaller juveniles to the time of recruitment to the fishery. In Troms, release of 1.5 year old juveniles with lengths of c. 32 cm resulted in recapture perecentages in the range of 7.5-15 %, indicating a much lower accumulated natural mortality on these fish (Pedersen 1997).

The mortality rate varied between areas, and in Ytre-Namdal, Masfjord and Øygarden only about 3-6 % survived from 1-group to the 3-group stage. In Heimarkspollen, survival was higher, probably due to lower abundance of large predatory fish and predatory birds and sea mammals in this area (Svåsand *et al.* 1998). The fishing mortality of recruited cod was high in all areas in western Norway and low in Ytre-Namdal and Sørfjord in Troms. The total instantaneous mortality rate after recruitment was high (>0.8 $year^{-1}$) in all areas except Troms, and far above the mean growth rate, leading to a rapid decrease in the biomass of the cohorts. In all areas in western Norway the fish were growth overfished. In Ytre-Namdal the fishing mortality of both released and local wild cod was very low (Kristiansen in press), indicating an underexploited stock. The natural mortality of large cod did seem to be large, and the biomass of the cohorts reached its maximum very early (1-2 group). In Troms the fishing mortality was also low (*c.* 0.20 $year^{-1}$) and the cod were probably underexploited (Pedersen 1997).

In conclusion, high natural mortality of small cod (<30 cm in length) in most areas led to a rapid decrease in biomass and numbers of the released cod. In western Norway releases of larger cod and reduced fishing mortality ought to have increased the yield. In Ytre-Namdal high natural mortality rates will lead to loss in biomass after release of all size groups. In Troms releases of large juveniles (31 cm) have given improved recapture ratios (Nøstvik and Pedersen in press). However, slow growth rates and relatively low fishing mortality rates of large cod did limit the potential yield from the releases in Troms (Svåsand *et al.* 1998).

Predation on cod

The main causes of mortality on young cod are probably predation by large cod and pollack (Salvanes and Nordeide 1993, Johansen *et al.* in press). In North Norway, the bull-rout (*Myoxocephalus scorpious*) was an important predator on wild and released cod juveniles (Leth 1995). In Øygarden, several thousands tags were found on a roosting site for cormorants and shags (Otterå *et al.* in press a) indicating that these sea-birds are also important predators on small cod. In Ytre-Namdal and Troms analysis of otoliths found in regurgitated pellets from cormorants have shown that cormorants consume large numbers of cod smaller than about 45 cm in length. In Troms, cod was a more important predator on 0-1 group cod while cormorants were most important for 2-4 group cod (Johansen and Pedersen in press). In these areas, sea-otters (*Lutra lutra*), harbour seals (*Phoca vitulina*) and grey seal (*Halichoerus grypus)* may be significant predators on larger cod. Predation by harp seals (*Phoca groenlandica*) on released and wild cod has been noted during the harp seal invasions of the coast of North Norway (Pedersen 1997).

Recapture rates and economic feasibility of releasing cod juveniles

The differences in recapture percentage between the release areas are related to differences in fishing pressure, size-selective fishery and variations in natural mortality. It appered that when individual growth rates were high, so was mortality (as in Øygarden). In areas with lower mortality and hence higher recapture percentages, the individual growth rate was lower (Heimarkspollen, Troms). If non-reported recaptures and tag-loss are included, the actual recapture percentages are probably 1.5 to twice as high as the recapture percentages reffered to so far in this report. However, profitability could not be obtained with the present cost of producing cod juveniles. The biomass of the recaptured cod was simply too low, even in the best experiments (Svåsand *et al.* 1998)

General conclusion of the cod stock enhancement experiments

In general, the results from the enhancement experiments with cod in Norway indicate that enough cod are recruited on average to use the production available for cod. Furthermore, the strong ontogenetic shift in the feeding ecology of cod means that large cod predominantly eat fish including smaller cod. This implies that negative feedback may be the result from a larger number of recruits released that will in turn cause increased predation mortality on the small cod. Despite relatively large variations in environmental conditions, cod production and fishing mortality along the Norwegian coast, the results indicate that under the conditions we have had during the 80s and 90s, releases of cod juveniles will not significantly increase cod production and catches.

Further prospects for cod and other marine species

Coastal ecosystem management

Knowledge obtained through the research programme PUSH has given us valuable insight into the natural regulation of fish production in our fjord and coastal areas. Moreover, the results have provided a better foundation for improved management of our coastal ecosystem, as well as a basis for future evaluations of proposals for sea ranching. This experience can also be used in further analyses, such as long-term studies of the effect of different management strategies performed on small local stocks. If so, studies of local stocks that are easier to monitor at lower cost could be useful means to increase the understanding of the larger migrating species, and thus contributing to improved management of our most important fishery resources.

Rearing of Atlantic cod

Recent experiments and financial analyses indicate that cod produced in sea cages (pens) have a profitable prospect. Important progress includes the use of light to inhibit sexual maturity. Increased fishing pressure due to recreational fishing and tourism on the local fishery resources can make releases of cod one way of increasing the attraction for tourism (Svåsand *et al.* 1998).

Critical success factors for stock enhancement of marine species

Species characteristics

Because of the high costs of producing and releasing fish or shellfish fry, the species used for sea ranching should have high survival, fast growth and high value when harvested. However, if survival is high, a lower growth and value can be defended. The costs of harvesting the animals should also be small. If the goal is to enhance the stock and to build up a new spawning stock, the future gains must be considered.

If the released fish shall increase the production and not compete with the wild stock there must be available carrying capacity. A wild stock may be below its carrying capacity due to recruitment bottlenecks or too small spawning stocks. Recruitment bottlenecks may be caused by factors like low temperature (lobster in Norway), unsuitable salinity (Baltic cod), limited spawning substrate (salmonids), or high abundance of predators during the early life stages. If the stock size is controlled by predators, most species usually reach a size refuge where they can resist most predators. This bottleneck can then be passed by releasing fish or shellfish that have reached the size refuge, but the increased costs of rearing larger individuals must be considered.

Another option is to control the predators, which also will enhance the wild stock, but this may often be too costly or not practical possible, and the effects will not always be predictable (Christensen 1996). When releasing cannibalistic species, like cod, the build up of large year classes of will have a negative feedback on younger age groups. Stocks with separate nursery and feeding grounds for the larger cannibalistic individuals should therefore be preferred. Food and space resources may also be a bottleneck in only a part of the animals life cycle. E.g. Atlantic salmon (*Salmo salar*) which have strongly limited food and space resources in the rivers, but get access to «unlimited» resources when migrating into the North Atlantic ocean.

Small broodstocks may be caused by overfishing or recruitment bottlenecks. In both cases releases may speed up the build up of the broodstock to a level with higher probability of recruitment success. The releases will, however, only have an effect if the natural- and fishing mortality of immature individuals is low, so that a considerable number will end up as spawners.

Considerations involved in an enhancement experiment
Before starting an enhancement or sea ranching activity several questions ought to be answered:

- What is the prize per released fish?
- How large yield per recruit is needed to make the releases profitable?
- What is the yield per recruit of wild fish of various sizes at recruitment to the fishery?
- What is the trophic links to the target species ?
- How close is the wild stock to its carrying capacity?
- Is there large variation in carrying capacity between years?
- Does the stock have recruitment bottlenecks?
- What is the maximum production capacity of the stock?
- How strongly is the stock exploited by man?
- How much of the stocks production is exploited by man and how much is eaten by other predators?
- At what size does the individuals reach size refuge from the most important predators?
- What is the relationship between size and mortality?
- Is the production regulated by predators or by low abundance of food?

Some of this questions can only be answered by pilot releases, but several of them may be adressed by analysis of data that may exist on wild stocks.

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Appendix

Appendix 1. Topographical characteristics, released numbers, mean sizes at release, and percentage recapture (min-max) for the main release areas with sub areas in Norway for artificially reared cod during the Norwegian Sea ranching programme (PUSH) (Svåsand *et al.* 1998). In addition were 40,000 reared cod tagged and released at the Norwegian Skagerrak coast in the years 1977-89 (Svåsand, in press).

Main areas	Sub areas	Coast	Fjord			Release		
			Area (km^2)	Max depth (m)	Sill depth (m)	Years 19xx	Mean sizes at release (cm)	Number Released
Austevoll[2,3,4,5]	Heimarks pollen	-	2.9	120	3	83-96	8-28	66,000
Masfjorden[6,7]		-	28.5	494	75	85-91	9-25	397,300
Øygarden[4,5,8]	Nautnes	exposed	-	-	-	88-95	12-41	250,000
	Sture	protected	-	-	-	88-95	25-27	8,400
Ytre Namdal[9]	Vikna Nærøy	Exposed	-	-	-	91-94	19-37	40,460
	Flatanger	Exposed	-	-	-	91-94	19-23	22,848
	Roan	Exposed	-	-	-	94	21	4062
	Sørsalten	-	15	180	4	94	24	9528
	Bølefjorden	-	7	132	7	94	20	3650
Vestfjorden[10]	Værøy-Røst	Exposed	-	-	-	93-95	20-24	7105
	Vestvågøy	Protected	-	-	-	93	36	500
	Nordsalten[11]					93-95	20-24	19,559
Troms [5,12]	Stålvikbotn	-	10.2	60	4	87-88	17-18	16,005
	Ullsfjord	-	400	280	-	90-94	17-34	78,311
	Sørfjord	-	54	130	8	89-94	17-33	63,188

[1]Only external (anchor) tagged; [2]Kristiansen and Svåsand, 1990; [3]Svåsand and Kristiansen 1990a; [4]Otterå *et al.*, 1997; [5]unpublished; [6]Aksnes *et al.*, 1989; [7]Fosså *et al.*, 1993; [8]Otterå *et al.*, in press-a, [9]Kristiansen, in press; [10]Skreslet *et al.*, in press; [11]Nordsalten consists of protected coastal area and a fjord (Sagfjorden), [12]Nøstvik and Pedersen, in press.