# An integrated development programme for marine stocking: the Norwegian example

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## ABSTRACT

In Norway a national sea-ranching programme was launched in 1990 financing release projects with the four species; European lobster (*Homarus gammarus*), Atlantic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*) and Arctic char (*Salvelinus alpinus*). The program aimed to elucidate biological, ecological, juridical and economic requirements for a new coastal industry. For one species, the lobster, the releases were done intending mainly to increase or enhance a local stock in a long-term perspective, while in the other three species the releases were made to evaluate the possibility to obtain a direct catch profit after a period spent in the ocean.

Knowledge acquired through the Norwegian sea-ranching programme PUSH has provided valuable insight into factors that regulate fish production in our fjord and coastal areas. It was not possible to develop commercial sea-ranching activities for any of the species concerned. However, biological and ecological requirements have been clarified. One of the prerequisites of stock enhancement and sea ranching is to be able to produce sufficient number of viable juveniles. This was accomplished for all species involved, and for some a further refinement to ensure higher survival and growth rate was suggested.

A total of 128 000 lobster juveniles were released from 1990 to 1994 and by the end of 1999 recapture percentage ranged from 2.2 to 9.2, although the recapture phase has not yet ended. Differences between wild and cultured lobsters have been found in claw morphology and abdominal width. However, the significance of such has not been possible to measure or even evaluate. It was shown that cultured lobster do not replace wild lobster, but represents an addition to the stock. It was also found that with the ruling minimum legal size MLS of 25 cm total length all females have spawned once before captured and a majority also twice. Furthermore, berried females of cultured origin have since 1995 made a significant proportion of the total number of berried females caught. Hence, the total stock has been strengthened but with the lack of appropriate management legislations it is uncertain of the long-term impact.

In various coastal and fjord locations 720 000 tagged cod juveniles were released providing valuable information on migration, survival and growth. Recapture

percentages ranged from zero to 30 percent depending on area, time and size at release. In most of the release areas, a positive correlation between the size at release and survival was found. Individual growth was highest in the outer coast areas. Ecosystem analyses were performed for the most important release areas and large differences were found in carrying capacity, growth and survival rates.

A total of 1.2 million Atlantic salmon smolts were released at four release sites. No systematic differences in recapture rate or straying could be found between releases made in watercourses at the coast and those in the fjord systems, but the geographical straying pattern differed between the specific release sites. In general, mean recaptures of year–classes of smolts were low, ranging from 0.5 to 3.8 percent. However, there was a high degree of variation between release groups; from close to zero to 12.8 percent total tag recovery. These differences, which seemed to be related to the treatment and origin of the released fish, probably indicates a potential for further optimisation of the methods of salmon sea ranching.

About 123 000 individuals of Arctic char were released, and in comparison with other salmonid species the recapture percentages were high, but somewhat variable. Ocean survival was strongly correlated with size or age of the fish. The bottleneck in sea ranching of Artic char is the high mortality in the first-time seaward migrants.

In general, survival rates in the sea were too low to make sea-ranching activity profitable, and the market price for Atlantic cod, Atlantic salmon and Arctic char would have to double or triple to make commercialisation worthwhile. However, reducing costs per animal released as well as including steps to improve survival and growth are possible approaches that can improve the prospects of profitability. Not even with the lobster does it look as though there be any development of private enterprises in the short run, although enhancement seems to have the potential to become socio-economically viable. In this respect, offspring or second-generation organisms must be taken into consideration and it is assumed that the effective or total production will increase as a result of the releases.

Despite the fact that evaluations of the economics of commercial sea ranching of Atlantic cod, Atlantic salmon, Arctic char and European lobster are discouraging, we should keep in mind that the work of the PUSH programme constituted the first attempts to evaluate large-scale releases of tagged individuals. This research activity might be characterised as trial and error experiments, and seven years is a short period in which to fully determine which ecological and physiological factors are decisive for growth and survival. To focus on recapture rates is short-sighted and ignores the fact that adequate knowledge of optimal times and places of release, not to mention the quality of the animals required to ensure high survival, was not available at the beginning of the 1990s. As Leber (1999) emphasises, stock-enhancement research shows many of the characteristics of a new science, and the data presented in this paper should be regarded as such.

## BACKGROUND

The oceans of the world offer a huge potential for increasing food production. During the past 150 years several projects have attempted to increase the yield from a fishery by releasing juveniles. The idea of stocking goes back to the 17th century, with the introduction of such techniques as transplanting fish and constructing artificial reefs in Japan and China. The first research activities on marine sea-ranching in Norway dates back to the end of the last century, when G.O. Sars discovered and described the early life stages of Atlantic cod (*Gadus morhua*) in 1864 (Sars 1879). In 1883 a marine hatchery was built in Flødevigen in southeastern Norway, marking the beginning of a boom in hatcheries that lasted for almost 100 years, with hatcheries also being built in the United States, Canada, the United Kingdom of Great Britain and other countries (Kirk, 1987). However, there was little or no evidence that these early stocking activities offered any benefits, and interest in these methods gradually faded. Recent experiments using marked larvae and juveniles have brought us information and knowledge that may explain the failure of these early stocking experiments (Kristiansen *et al.*, 1997). Until quite recently, a bottleneck in the use of larvae and small juveniles in stocking studies has been the lack of suitable tagging techniques.

Interest in sea ranching was aroused again in the 1980s, along with the development of suitable marks and tagging methods. In Norway tagging and release programmes were launched using smolts of Atlantic salmon (*Salmo salar*) and Atlantic cod juveniles, and some release experiments were also carried out using juveniles of the European lobster (*Homarus gammarus*), though these were released without physical tags. Promising initial results formed the basis for a larger national sea-ranching programme, which is described below.

### The Norwegian sea-ranching programme (PUSH)

In spring 1989 the Norwegian Ministry of Fisheries and Ministry of the Environment decided to appoint a committee of scientists to assess, from a biological point of view, the potential for sea ranching anadromous fish species in Norway. The committee recommended that all on-going as well as commencing projects should be coordinated by a national sea-ranching programme. On September 6, 1990 this became a reality when the Norwegian Government resolved, with the approval of Parliament, to launch a Norwegian Sea Ranching Programme (PUSH) (Anon., 1989; Anon., 1990). This would involve not only anadromous species such as Atlantic salmon and Arctic char (*Salvelinus alpinus*), but also Atlantic cod and European lobster. A board was appointed with representatives from industry, research institutions and management, while steering committees were set up for each of the four species, with representatives from all parties involved, and with funding from PUSH. The steering committees met several times a year to discuss results, progress and problems. It was regarded as fruitful for the progress of the projects that various parties participated in the meetings so that questions and problems could immediately be clarified. The steering committees have also been in charge of the final species reports (Anon., 1998a; Borthen *et al.*, 1998; Skilbrei *et al.*, 1998; Svåsand *et al.*, 1998a). The proposed timeframes varied from five to seven years, but in practice the individual projects lasted for seven years, except for char.

In total the Norwegian sea-ranching programme (PUSH) funded 40 individual projects between 1990 and 1997. The annual budget varied from 7 to 39 million NKr, with a total of 178 million NKr (lobster 19 million; cod 63 million; salmon 58 million; char 20 million; analysis of economics and management, and miscellaneous projects 8 million; administration 10 million) (Anon., 1998b).

### AIMS

The programme aimed to elucidate the biological, ecological, juridical and economic requirements of a new coastal industry based on sea-ranching European lobster, Atlantic cod, Atlantic salmon and Arctic char. The long-term goal was to develop release and harvesting methods that would be economically viable and ecologically justifiable.

Sea ranching is defined as the "economical exploitation of a potential product in the sea by releasing cultured organisms that are to be harvested and sold". However, wild juveniles have also been used in some of the release experiments. A distinction should be made between releases that are intended to increase or enhance stocks in a longer-term perspective in order to increase the potential future yield (stock enhancement), and releases made to obtain a direct catch profit after a period spent in the ocean (sea ranching). Both strategies have formed part of the programme that also aimed to stimulate the cultivation of char and cod in particular.

## BIOLOGICAL AND POLITICAL CONSIDERATIONS

The last 25 to 30 years of development in intensive coastal aquaculture have indicated certain limitations of the marine environment. More extensive forms of aquaculture might therefore assume greater importance in the future. Parliamentary White Paper (St. prp.) No.95 (1989–1990) says Anon., 1989 translated from Norwegian):

> *"Sea ranching will be based on nature's own carrying capacity, where the harvesting of resources is adapted to the ecosystem."……"One might also be optimistic regarding the prospects of developing aquaculture as a means of strengthening traditional fisheries through stock enhancement, at least within local stocks."……"Released fish will contribute to local stocks in the fjords and near coastal areas".*

There was a strong incentive to stimulate the development of business activities in coastal rural areas, in order to improve the economic situation in these areas. In 1988 Norway adopted a ban on using driftnets for catching salmon, though with strong objections from fishermen, and there was a need to make amends for this ban. Sea ranching of salmon in Norway, has been carried out in rivers since the last Second World War, but it was not until after the 1950s that it became systematic, with the adoption of a scientific approach. Tagging of hatchery-reared smolts showed that adults returned with high precision to their point of release in rivers or estuaries. Releases of salmon smolts directly into the sea increased recaptures of adults but also increased straying because mature fish had no "native" river to return to. The main strategy adopted for future salmonid ranching in Norway was therefore to release smolts in relation to freshwater, i.e. in rivers or in estuaries close to river mouths.

Lobster, cod and salmon stocks had all been descending during the ten years before PUSH started. In the late 1980s there was a severe reduction in Atlantic cod stocks in Norwegian waters, and lobster stocks were also at a critical level. It was believed that it would be possible to re-establish production back to "normal" levels. Prices were high in the late 1980s, and viable economic activity was assumed to be achievable. Highest prices were obtained for lobster, for which fishermen were paid from 150 to 240 NKr per kilogram, i.e. about US$20 to US$30. In the period before 1990 several stocking experiments were carried out, with promising results for all four species. With regard to char, a common species in northern Norway, there was a desire to involve this part of the country as well. These factors formed an important background for the proposed PUSH programme, as it was presented in 1989. The following sections present a survey of the results concerning the individual species involved in the PUSH programme.

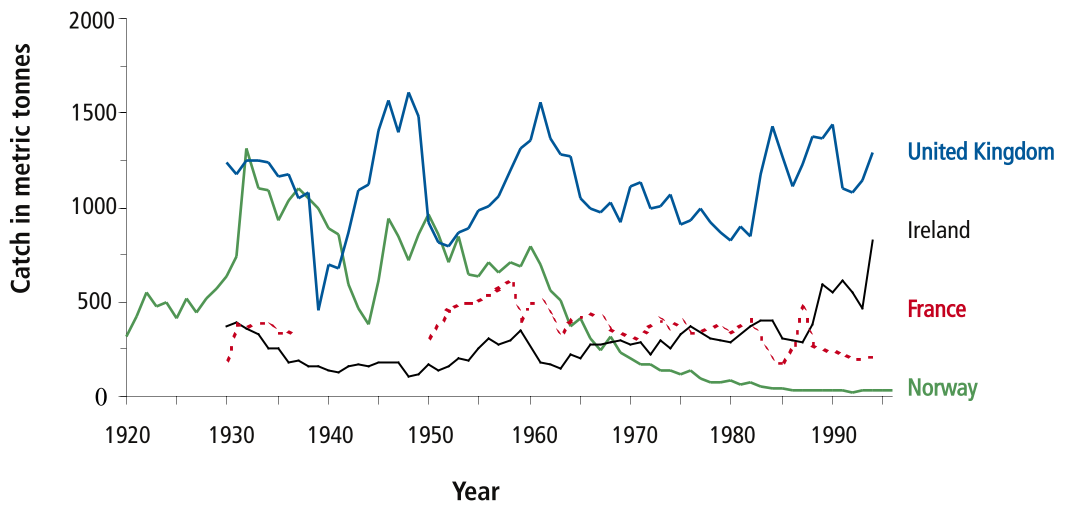
# European lobster *(Homarus gammarus)*

## REVIEW OF FISHERY

Stocks of European lobster have supported valuable local fisheries in Norway since around 1600 (Boeck, 1869; Dannevig, 1936). Available statistics show that between 1815 and 1930 annual landings fluctuated around an average of about 900 000 individuals (about 500 tonnes). At that time there were no restrictions in the fishery, which became an issue to be questioned for hundreds of years. In 1932 landings rose sharply to a peak of 1 300 tonnes or about 2.8 million individuals (Figure 1), partly as a result of good recruitment in south-western Norway (Dannevig, 1936) and partly because of an increase in fishing effort off the Norwegian Skagerrak coast (Tveite, 1991). After the Second World War landings fell slowly until the early 1960s. However, since the 1960s there has been a severe reduction in the annual harvest, which currently lies at about 30 tonnes. The Norwegian share of European lobster landings varied from 20 to 50 percent before 1960, whereas it was only about 1 percent in 1996. No other country in Europe has experienced such a dramatic decrease in its lobster harvest.

Stock management legislation in Norway has been based on closed seasons and minimum legal sizes (MLS). A close season was introduced in 1849, and is currently set from 1 June to 30 September. In 1879 the MLS was set to 21 cm total length (~71 mm carapace length (CL)) and 85 years later, in 1964, was increased by 1 cm (~75 mm CL). The unwise management strategy of fishing females before maturation was pointed out by fisheries scientists many years ago (Boeck, 1869; Appelöf, 1909), but the suggestions of an MLS of 25 cm TL (~88 mm CL) in western Norway and 24 cm TL in southern Norway were not enforced until 1993. By contrast, from 1951 until 1966 the United Kingdom banned landings of berried females (Bennet and Edwards 1981), and for almost 40 years the MLS in the United Kingdom of Great Britain and Northern Ireland has been greater than 80 mm CL (~23 cm TL), i.e. in accordance with size at maturation, as reported by Free, Tyler amd Addison (1992). This has probably made United Kingdom stocks less vulnerable to overfishing.

FIGURE 1. Reported landings of European lobster (*Homarus gammarus*) in Norway, the United Kingdom (England, Scotland, Wales and Northern Ireland), the Republic of Ireland and France from 1920 to 1994 (data from Directorate of Fisheries in Norway, Dow, 1980; FAO, 1981–1996)



## REVIEW OF PREVIOUS CULTIVATION PROJECTS

In the mid-1880s G.M. Dannevig hatched larvae of the European lobster at Flødevigen in southern Norway, and he was the first to obtain survival until settlement (Appelöf, 1909). More or less at the same time, larvae from the closely related American lobster (H. americanus) were being hatched in Woods Hole, United States (Aiken and Waddy, 1995). Interest in stocking fishing grounds with hatchery-reared larvae/juveniles grew when lobster landings in Canada and Newfoundland declined dramatically during the 1880s (Waddy and Aiken, 1998). There was general concern in Norway when lobster landings also declined on this side of the Atlantic in the same period, the 1880s. In the early 1900s a large number of hatcheries were established in the North American continent as well as in Europe (Aiken and Waddy, 1995). On the eastern coast of the United States alone some 880 million newly hatched larvae were released between 1885 and 1903. In western Norway a large holding facility was built at Kvitsøy, one of the major lobster fishing areas. The purpose was to maintain berried females until hatching, and with this effort increase the total recruitment in the area (Appelöf, 1909). Large numbers of newly hatched larvae were subsequently identified, but older ones were never found. Although a few young lobsters were found in the holding facility four or five years later, and most likely having grown up there, the conclusion was that this gave few measurable results. Further effort was therefore dedicated to improve hatching techniques, but it was not until in 1923 that a method of mass-producing newly settled larvae was developed. In the same year, a lobster hatchery was built in Flødevigen in southern Norway, but as previously noted, in France and the United Kingdom of Great Britain and Northern Ireland several hatcheries had already been set up. However, common features of all of these stocking projects around the world was the lack of methods for identifying the cultured and released animals and thus proves that they could survive until recruitment to the fishery.

Further progress in this matter was not made until the mid-1970s. In Canada, several private companies aimed to commercialise lobster production, but unfortunately none were reported as successful (Waddy and Aiken, 1998). In Norway, S. Grimsen and J.G. Balchen, on behalf of SINTEF (Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) and the tobacco company Tiedemanns, successfully raised approximately one-year-old lobster juveniles for release purposes. This resulted in the establishment of a lobster hatchery at Kyrkesæterøra in mid-Norway. Tveite and Grimsen (1995) reported that from 1979 to 1987, 62 500 lobster juveniles were released on the Norwegian coast, from Bulandet in the mid-west to Kragerø in the southeast of the country. As a result of the cultivation process a majority of these animals developed two scissors claws instead of the normal set of one scissors and one crusher claw. These were commonly called "Tiedemanns lobsters", and after five to eight years could be recognised in the commercial fishery. In some areas, fishermen reported a substantial increase in their catches due to "Tiedemanns lobsters" (Tveite and Grimsen, 1995).

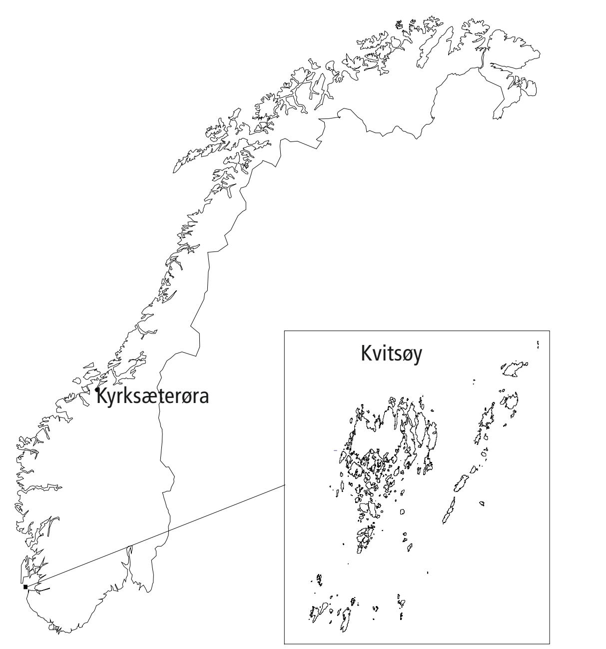
In the mid-1980s tagging using magnetically binary-coded tags was also found to be suitable for juvenile lobsters (Jefferts *et al.*, 1963; Wickins *et al.*, 1986). This development finally made it possible to evaluate lobster release programmes quantitatively, and triggered a number of release experiments in France (Latrouite and Lorec 1991, Latrouite 1998), Wales (Cook, 1995; Bannister and Addison, 1998), England (Bannister *et al.*, 1994; Bannister and Addison, 1998), Scotland (Burton *et al.*, 1994), Ireland

(Browne and Mercer, 1998) and Norway (reported here). In 1989, the Institute of Marine Research in Bergen (Norway) took over the Kyrkesæterøra Lobster Hatchery in mid–Norway, and in the following year the European lobster was included as one of the four species in the Norwegian Sea Ranching Programme (PUSH).

## METHODOLOGY OF THE STOCK-ENHANCEMENT PROJECT

The choice of the large-scale release area fell on Kvitsøy, a group of islands near the opening of Boknafjord in southwestern Norway (Figure 2). This choice was based on a number of factors. The islands are separated from surrounding areas by deep-sea trenches, and out-of-area migration was expected to be a minor problem. Kvitsøy is also known for its historically high catches of lobster and must once have sustained a large population, as well have been very productive with respect to settlement of naturally produced larvae. However, the present situation is very different. Landings are extremely low compared to earlier times, and there are indications of a long-lasting failure in recruitment. Selections of broodstock, larval rearing, release strategy etc. are outlined below. For more detailed information see Uglem and Grimsen (1995), Uglem *et al.* (1995), Borthen *et al.* (1998) and Agnalt *et al.* (1999).

FIGURE 2. The lobster hatchery at Kyrksæterøra, Norway, and the release site at the Islands of Kvitsøy




## BROODSTOCK SELECTION

Wild berried females were captured at Kvitsøy by local fishermen and sent to the hatchery at Kyrksæterøra (Figure 2). In some seasons there were difficulties in obtaining sufficient numbers of ovigerious females, and in the early phase of the project supplies were made from elsewhere in regions around Kvitsøy, and berried females were even introduced from Scotland. Offspring from the Scottish broodstock were not intended to be released at Kvitsøy, although this may have happened unintentionally in the first release year, though at any rate only in small numbers (S. Grimsen and I. Uglem personal communication, 2000). Since 1991, only berried females from Kvitsøy have been used as broodstock. After hatching, the broodstock females were released back to the islands of Kvitsøy.

## LARVAL REARING

A detailed description of the processes that took place in the hatchery and nursery is provided by Grimsen *et al.* (1987), Uglem and Grimsen (1995) and Uglem *et al.* (1995), but these followed Wickins *et al.* (1986). The hatchery was supplied with water heated through a heat-exchange process with thermal effluent from the local ferro-silicon smelter, Hølla Smelteverk. On arrival, the berried females were placed in individual compartments. Hatched larvae were collected in a net-screened box before transferred to large rearing tanks (250–350 litres) with continuous water flow. The larvae were mainly fed frozen adult brine shrimp (*Artemia* spp.). When the larvae reached development stage IV, the last pelagic stage before settling, they were transferred to trays with separate divisions. Each tray, containing 120 individuals, was put into a circular pool with a diameter of 50 m. The pool was divided into 11 concentric rings, and the trays circulated within each ring. From 1990, shell sand was added in the settling phase to induce the development of a crusher claw (Wickins *et al.*, 1986; Korsøen, 1994). The large-scale hatchery aimed to produce annually from 50 000 to 70 000 nine-month old juveniles. However, although a high survival rate was obtained in the small-scale research facilities, survival in the large-scale hatchery remained low, at only three to five percent. Nevertheless, sufficient numbers of juveniles were produced to carry out large-scale releases at Kvitsøy (see Table 1).

TABLE 1. Total number of cultured lobster juveniles released at Kvitsøy from 1990 to 1994, and number recaptured from autumn 1992 to autumn 1999 (updated and modified from Agnalt et al., 1999). Number recaptured is separated into above minimum legal size (MLS; commercial landings) and below MLS (selected samples)

| Release Year | Hatching year | Number tagged | No. recaptured above MLS | No. recaptured below MLS | Total recapture % |
|---|---|---|---|---|---|
| 1990 | 1988 | 14 977 | 523 | 21 | 3.6 |
| 1990 | 1989 | 8 726 | 774 | 48 | 9.4 |
| 1991 | 1990 | 29 693 | 1 607 | 103 | 5.8 |
| 1992 | 1991 | 29 919 | 1 894 | 205 | 7.0 |
| 1993 | 1992 | 11 784 | 523 | 64 | 5.0 |
| 1994 | 1993/94 | 32 846 | 668 | 108 | 2.4 |
| | | 127 945 | 5 989 | 549 | 5.1 |

## TAGGING METHOD AND RELEASE STRATEGY

Before transportation to the release area, a magnetically coded microwire tag (North West Marine Technology Inc.) was injected into the base of the 5th pereiopod. The tags were 1 × 0.5 mm or 0.5 × 0.5 mm in size, and could only code for batches or groups of lobster. Uglem and Grimsen (1995) reported a tagging mortality from one to four percent, and a tag loss of about 10 percent after three months, which is in accordance with previously reported figures (Wickins *et al.*, 1986; Latrouite and Lorec, 1991; Burton 1992). The lobster juveniles were released by fishermen at sea surface along the shore at depths no greater than 10 m. This release strategy is rather crude in comparison with releases made by divers, or if juveniles are sent through a tube as done e.g. in Great Britain (Bannister and Addison, 1998). However, this strategy was evaluated as the only practical method to release such a large number of juveniles in as short a time as possible. In the period from 1990 to 1994, a total of 128 000 juveniles were released, of which 125 600 were tagged (Table 1). Little was known of the optimal habitat requirements of these juveniles, and emphasis was placed on releasing lobsters in a number of different localities.

### Management of the recapture phase

Commercial landings in the release area were closely monitored every year from 1991 for micro-tagged survivors, i.e. lobster above the minimum legal size. All lobsters caught were run through a micro-tag detector (tubular or hand-held wand detector) to identify animals of cultured origin. This was done in close cooperation with fishermen, but also involved personnel from Kvitsøy municipality. This cooperation proved to be extremely fruitful, and since 1995 between 95 and 99 percent of all lobsters caught in these islands have been run through the micro-tag detector. Samples below minimum legal size were also collected, but after recording biological data most of the lobsters were tagged and returned to the sea. However, since 1995 a sub-sample of cultured lobsters below legal size has been taken in order to identify release groups. For each lobster sampled (both above and below legal size) all necessary data were obtained, including time and place of recapture as well as biological measurements. Micro-tagged survivors above legal size were bought from fishermen at market price with an additional bonus of NKr 25.

### Genetic monitoring

Cultivation might unintentionally lead to genetic changes in reared animals compared to the wild native population. This has been a problem for most species under domestication/ cultivation for stock-enhancement purposes (Allendorf and Ryman, 1987). When the genetic investigations in the Kvitsøy project started in 1991, few genetic studies had been carried out on European lobster. Tracey *et al.* (1975) performed some genetic analyses on the related American lobster and Hedgecock *et al.* (1977) compared the two species. In this stock-enhancement project, using tissue samples of wild-caught lobster, wild-berried females that were used as broodstock, produced offspring as juveniles and as recaptured survivors that have and are still being collected. The analysis is based on genetic variation in enzyme systems as expressed in white muscle tissue. In the early phase of the project, tissue samples from brain, gills, hepatopancreas, heart and eye were collected as well, but as similar results were obtained they were found to be less suitable because the animals then had to be sacrificed. White muscle tissue was collected from one of the periopods or walking legs because these legs will grow back to normal size in one or two growth seasons. The samples were screened by starch-gel electrophoresis using various buffer systems and enzyme staining protocols (Jørstad and Farestveit 1999). Of 22 different stained allozymes, variation was found in only four enzymes: glucose phosphate isomerase (GPI), isocitrate dehydrogenase (mIDHP), phosphoglucose mutase (PGM) and malic enzyme (sMEP). These represent five different enzyme loci, and all main samples collected during the project have been screened with respect to the above-mentioned enzymes.

### Fish/crustacean health management

Norwegian law requires that aquatic animals, including lobsters, being transported across regional boarders in Norway have a health certificate to avoid the spread of disease. For this reason, broodstock used in this enhancement project were checked for disease before transport to the hatchery in mid-Norway, and also before they were transferred back to the capture area. The juveniles produced were also subject to the same procedure, and were checked before being transported to the release areas. In the hatchery, the only disease reported was infections with the bacteria Leucothrix mucor, which caused an increase in egg mortality. This bacterium was a problem in only a few instances, and the infection was treated with 1.5 percent Buffodin.

## EVALUATION PROGRAMME

### Enhancement goals

As described in a previous section, the Norwegian lobster fishery decreased drastically from the 1960s and onwards and has in fact remained at a very low level since the 1980s. The main goal of the stock-enhancement programme was therefore to investigate whether cultivation approaches could increase the overall recruitment in a local stock, and to assess whether the stock could be rehabilitated or at least strengthened on a long-term basis. Another important objective was to evaluate the economic potential of releases of juveniles for sea ranching or private business activities.

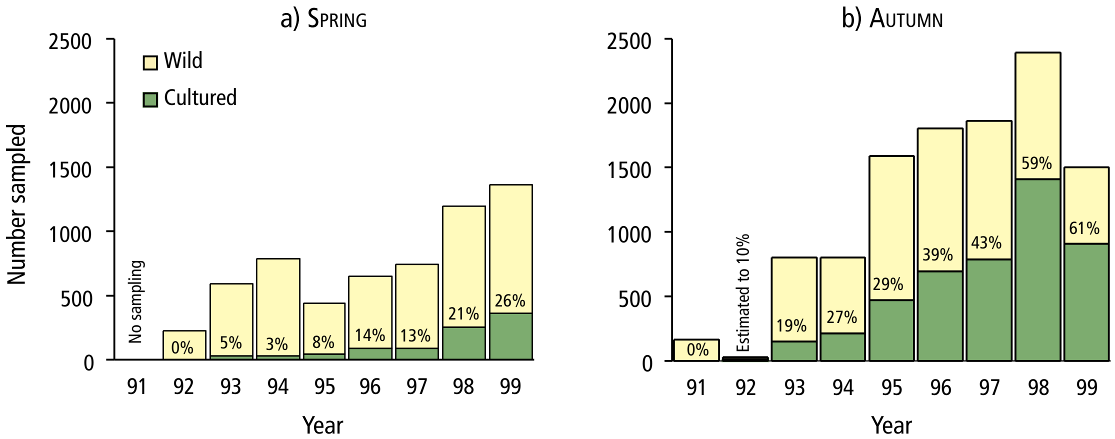
### Measures of success

How can success be evaluated or assessed? As pointed out by Cowx (1994) this question must obviously be related to the objectives of stocking, whether it is for enhancement or restoration purposes or for the creation of new fisheries. An important part must involve identification of what contributes to success or failure. In general, strengthening of a stock or population would require cultured animals to survive long enough to reach age or size at maturation and contribute to the overall recruitment. It is also important that the releases should not induce negative effects upon the native stock. An assessment of potential risks should include an evaluation of genetic changes as well as ecological interactions such as evaluation of the carrying capacity of the system, species interactions and control of diseases (Laurec, 1999). In this enhancement project we chose to monitor commercial landings in order to estimate the contribution of cultured lobsters in each fishing season. Given the historical information of previous landings, the carrying capacity is assumed to be unsaturated. We regarded it as important to determine whether hatchery reared lobsters differ from wild and native lobsters with respect to population parameters such as reproduction, growth and survival, as well as to determine whether replacement might have taken place. Measures have also been taken to assess possible genetic changes.

### Contribution of cultured lobster to fishery

A sample of commercial landings was collected in each fishing season, i.e. spring (April to end of May) and autumn (October to February, no catches were reported in March). Selected fishermen recorded a representative sample of lobsters below the legal minimum size from their autumn catches. However, in 1997 few fishermen delivered samples below the legal size, and in 1998 very few lobsters could be registered due to lack of sufficient personnel from the Institute for Marine Research (IMR) – the fishing season started with enormous catches and the personnel had to prioritise legal sizes. Above the legal size, the proportion of cultured lobsters in commercial catches has increased since the monitoring programme started in 1991 (Figure 3). There was a clear increase in both the spring and autumn of 1998, when cultured animals made up 21 percent of the spring catches and 59 percent of the autumn catches. Fewer cultured lobsters are caught during spring than autumn, but this merely reflects a different fishing pattern. The lobster pots are set at more weather-exposed parts of the islands during spring, whereas the majority of the releases have been made in sheltered areas that are mainly fished during the autumn (Agnalt *et al.*, 1999). Cultured lobsters have also made up a substantial proportion of the recruiters (Figure 4). An increase was observed until 1996/1997, while a decrease was noted in 1998. This is in accordance with observations of which release groups or year classes are present in the catches related to number released.

FIGURE 3. Sampling of commercial landings of European lobster (*Homarus gammarus*) above legal size at Kvitsøy during (a) spring and (b) autumn, separated into wild and cultured lobster (updated from Agnalt *et al.* 1999). The proportion of cultured lobsters is given above the column. Note that the minimum legal size changed from 22 to 24 cm total length on 1 October 1992, and to 25 cm on 1 October 1993. Data for autumn 1999 are preliminary results because not all information has yet arrived at the Institute of Marine Research




There has been an increase in fishing effort from 1991 to 1999, probably as a result of the enhancement programme. The observed high frequencies of cultured lobsters in the landings could therefore be explained by displacement of wild lobsters in the area. For this reason, some reliable fishermen were contracted to keep logbook of daily catches during the commercial fishing season. Information regarding catches of lobster above and below legal size and the number of lobster pots used was recorded daily. Catch per pot lift was estimated for the five or six fishermen (somewhat variable from year to year) with the highest catches during the autumn fishery, and an average was preferred to simple pooling in order to avoid overemphasising the influence of single data (Agnalt *et al.*, 1999). Since 1995 the same six fishermen have been contracted. Soak time is ignored since 99 percent of the reported catches were made in pots soaked for one or two days, and no differences in catch ability could be found between pots soaked for one, two or three days. Catch per pot lift shows an increase in the proportion of cultured lobsters in the landings, especially in 1998 (Figure 5), as is also shown in IMR's sampling programme. Catches of wild lobster have remained more or less at the same level since 1995. There seems to be a correlation between mean temperature in October and November and autumn landings of wild lobster, although this might also coincide with responses to various stock-management restrictions. The

FIGURE 4. Sampling of lobster below legal size of European lobster (*Homarus gammarus*) during the commercial fishing season in autumn at Kvitsøy (updated from Agnalt *et al.*, 1999). The proportion of cultured lobsters is given above the column. See text for explanation for low numbers sampled in 1997 and 1998

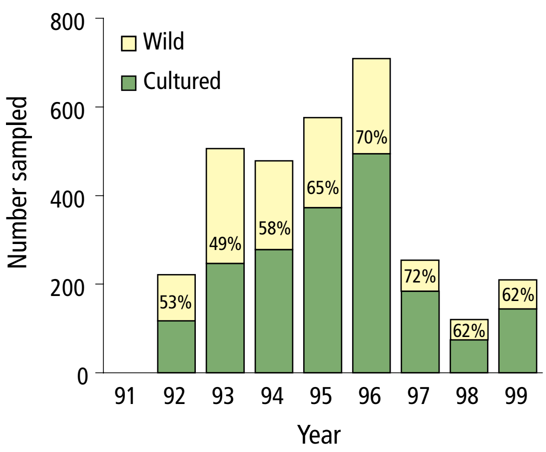
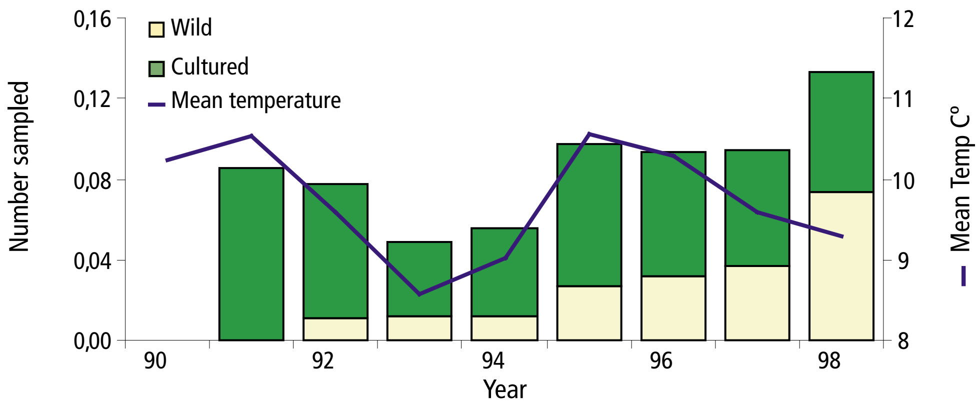


FIGURE 5. Catch per pot lift of lobster above legal size caught at Kvitsøy each autumn season. The catches were separated into wild lobster and lobster of cultured origin. Note that the minimum legal size changed from 22 to 24 cm total length from 1 October 1992, and to 25 cm from 1 October 1993. The solid line indicates mean surface temperature in October and November at Kvitsøy (data provided by Mr S. Meling, Kvitsøy)




drop in the landings in 1992 and in 1993 is possibly due to a fall in mean temperature, but might also reflect the rises in minimum legal size (MLS) of 3 cm total length (TL), i.e. from 22 to 24 cm TL in 1992 and to 25 cm in 1993. The increase in the catch per pot lift in 1995 is likely to be because of the high sea temperature, but could possibly also be due to an accumulation of recruiters because of the previous years' increase in MLS. A correlation between lobster landings and temperature has previously been noted, e.g. by Dow (1980) and Koeller (1998).

Mr S. Tveite (Institute of Marine Research, Flødevigen Marine Research Station) provided data of catch per pot lift for a variety of locations along the southwestern coast of Norway (Tveite, 1991; Tveite, unpublished data). When pooling this information a very similar exploitation pattern can be seen for wild-caught lobster at Kvitsøy and elsewhere in southwestern Norway (Figure 6). We interpret this as an indication that wild lobsters at Kvitsøy have not been displaced, and that the observed increased landings are due to survival of the cultured lobsters. However, catch per pot lift is lower at Kvitsøy compared to the other areas, and the reason for this has not yet been explored in detail, but might reflect temperature differences. Kvitsøy is located at the outer mouth of a large fjord and is thus very weather exposed, while the other areas are located further south, with generally higher sea temperatures.

FIGURE 6. Number of lobsters caught per pot lift of wild lobsters at Kvitsøy (as in Figure 5), and elsewhere in western Norway (Tveite, 1991, and unpublished data)

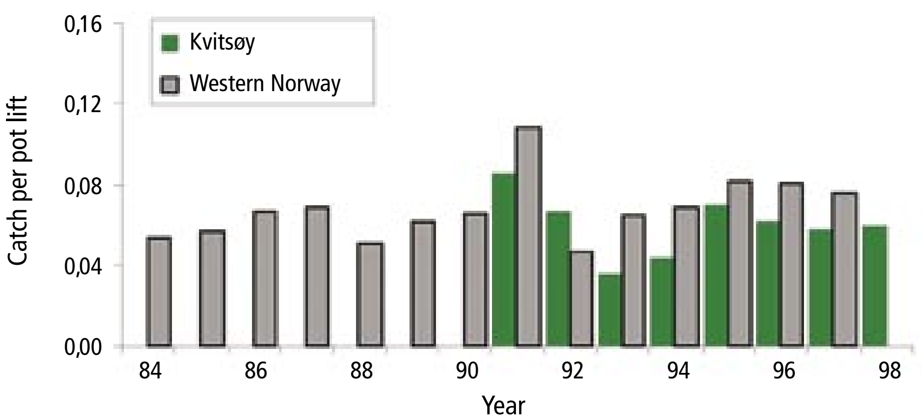
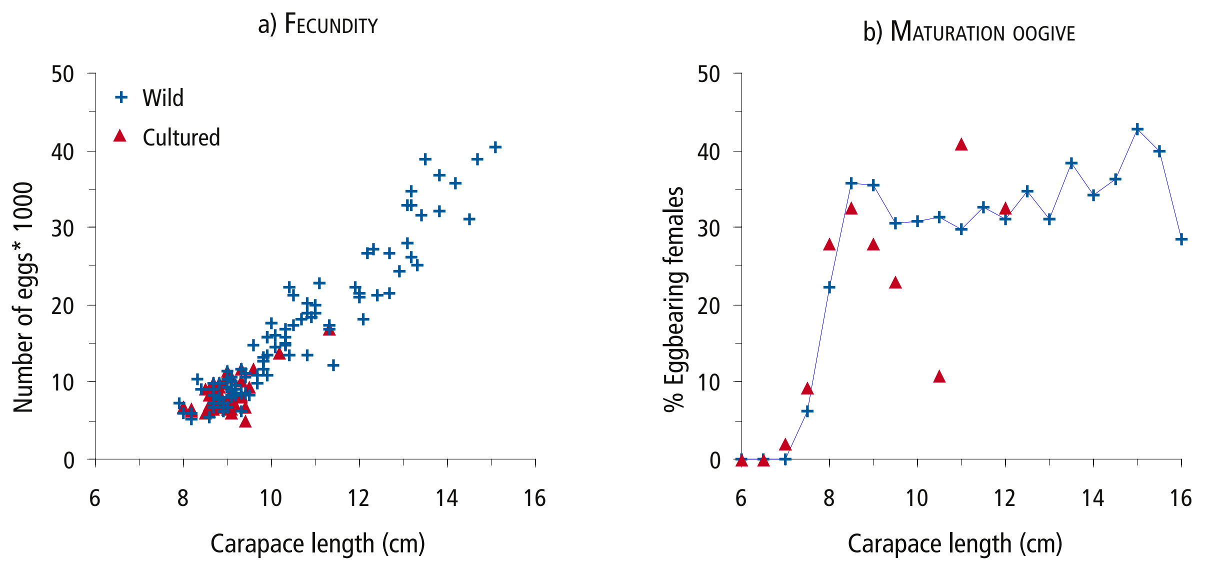


TABLE 2. Summary of lobster-release programmes in Europe. Data from France, Ireland and the United Kingdom are from Gendron (1998). All release programmes, except the one in Norway, ended when recaptures reached zero. The recapture period in Norway includes data until 31 December 1999. Recaptures could not be reported on two occasions since the released lobsters were too small to be tagged

| Country | Release year | Recapture year | Number released | Age at release | Number recaptured | Number of berried females | Total recapture % |
|---|---|---|---|---|---|---|---|
| France | 73–83 | | 100 000–225 000 | 2–3 weeks | | | |
| France | 84–87 | 87–89 | 25 480 | ~1 year | 22 | | |
| Ireland | 93–97 | | 292 000 | 2–4 weeks | | | |
| UK | 83–88 | 88–93 | 49 128 | ~1 year | 653 | 18 | 1.3 |
| UK | 84–88 | 88–94 | 19 233 | ~1 year | 453 | 20 | 2.4 |
| UK | 84–90 | 85–93 | 3044 | ~1 year | 58 | | 1.9 |
| UK | 84–89 | 85–93 | 19 520 | ~1 year | 307 | | 1.6 |
| Norway | 90–94 | 92–99 | 127 945 | ~1 year | 6 538 | 980 | 5.1 |

A total of six year-classes were released during the five-year period from 1990 to 1994. The releases in 1990 consisted of two year-classes, (88 and 89), that appeared for the first time in the commercial landings in autumn 1992. In the two years since the release, the lobsters had grown from a release length (TL) of 3 to 6 cm to a recapture length of 23 to 25 cm. They had also obtained a body weight of 400 to 500 grams in this short time period. The so far largest recaptured lobster weighed 1.9 kg. The highest recapture percentage obtained is 9.4 percent for the 89 year-class, whereas recaptures of the 90 and 91 year-classes dominate in terms of numbers (Table 1). The 92 and 93 year-classes have commenced to recruit to the fishable part of the stock. Since they made up 35 percent of the total number released, and samples below legal

FIGURE 7. Differences between cultured and wild female lobsters with respect to (a) fecundity (samples collected during autumn 1996 and spring 1997) (Agnalt, unpubl. a) and (b) maturation ogive (data pooled from autumn 1991 to autumn 1998 to avoid year-class differences; each point is based on a minimum of five observations) (Agnalt, unpubl. b) in comparison with a reference sample of wild lobsters collected during the same fishing season.



size confirm survivorship, recapture is expected to increase in the years to come. By autumn 1998 all year classes are present in samples above legal size, although the first and the last (88/89 and 93) have been found only in small numbers. At Kvitsøy, about 21 700 lobsters had been checked by 31 of December 1999 for cultured survivors, and among these 6 538 released individuals were identified. This means, an overall recapture percentage of 5.1, but this will increase as the recapture period has not yet ended. The monitoring programme will continue until 2001. The present recapture percentage is already substantially higher than in other release projects elsewhere in Europe (Table 2). With respect to berried females of cultured origin, 980 individuals have been caught at Kvitsøy, compared to only 20 in the four release areas in the United Kingdom of Great Britain and Northern Ireland. None of the other enhancement studies has included estimates of tag loss into final recapture rates. We have partly accounted for some of the tag loss by including lobsters that developed double scissors claws during the nursery period and for unknown reasons thereafter lost their tags.

The possibility of out-of-area migration has been considered in the project, and catches from five to six locations in the surrounding areas to Kvitsøy have been investigated every autumn season since 1995. So far, no micro-tagged survivors have been detected in these surrounding areas.

### Interaction with natural populations

As the main goal of the programme is to strengthen a stock on a long-term basis, it is important to evaluate if there is a contribution made by the cultured animals to the total reproduction of the stock concerned. Emphasis must also be placed on evaluating possible interactions with native lobsters, and assessments of population parameters such as maturation, growth and survival must be made.

Studies of the number of eggs produced by wild and cultured females were made in autumn 1996 and spring 1997, and no differences could be found (Figure 7a). However, cultured lobsters had not yet grown to sizes larger than 12 cm carapace length. The maturation oogive shows similar patterns of maturation for wild and cultured animals, although in the maturing phase there is tendency towards a higher percentage among cultured females at each length group (Figure 7b). For larger sizes a lower percentage among cultured females probably describes the reproductive status of one or two year-classes rather than the average. On the other hand, wild females are represented as a pool of an unknown number of year classes. The production cycle means that not all females reproduce every year, and therefore there is no length group in which all females are berried at the same time. Furthermore, berried females of cultured origin have been present in landings since 1993, and since 1995 they have made up a significant proportion of the total number of berried females caught (see figure 28.5 in Agnalt *et al.*, 1999). A tagging experiment started in July 1996, focusing on growth and survival. Recaptures obtained so far indicate a higher growth increment at each moult in males than in females, though so far there are no differences between wild and hatchery animals. More information is being collected to confirm or reject this trend. It has been shown that with the present MLS of 88 mm CL, all female lobsters have spawned once before capture, and a majority have done so twice.

Morphological differences between cultured lobsters and their wild conspecifics have been found. Preliminary investigations of claw morphology indicate that cultured lobsters have developed slightly longer claws (both crusher and scissors), and females of cultured origin have a tendency to be smaller or slimmer in the second abdominal width (applied as a secondary character to evaluate onset of maturation). It must be pointed out that this analysis is still at a preliminary stage. In addition, Agnalt *et al.* (1999) reported that lobsters with double scissors claws were more prone to be caught than animals with the normal set of one crusher and one scissors claw.

### Genetic aspects

The results of the analyses of tissue samples collected from wild lobsters, wild lobster broodstock and offspring as juveniles have been tested with respect to possible genetic changes in the last three production years, i.e. 1992, 1993 and 1994. For the 1992 production, from which juveniles were released in that year, no genetic changes were found in allele frequencies at any of the allozyme loci when all three samples were tested. Pairwise testing revealed small but statistically significant differences between the produced juveniles and the reference sample taken from the wild population. For the 1993 production no significant genetic changes were found in any of the loci investigated. However, for the last juvenile production in 1994, both the wild broodstock and the juveniles later produced. The results clearly demonstrate that significant genetic changes in allele frequencies, even as small as those observed here, are also likely to occur in lobster cultivation. As in other species the risk of unwanted changes is clearly dependent on the numbers of broodstock actually used (genetic drift), and in differences between wild and farmed environment (selection).

### Economic analysis (cost/benefit)

During recent years some attention has been given to evaluations of economic aspects of sea ranching and marine stock-enhancement projects (Moksness and Støle, 1997; Hilborn, 1998; Moksness *et al.*, 1998), but very few species or stocking programmes have been found to be economically viable. Within the PUSH programme economic analyses have been regarded as important goals. The lobster stocking project applied the software package Powersim® (Cover 1996), and the simulation model was called LOBST.ECO that is described in more detail by Borthen *et al.* (1999). There are separate modules for wild and cultured lobster, and males and females are separated for each variable. Since cultured lobsters make a substantial contribution to the overall reproductive potential at Kvitsøy, it was considered essential to evaluate the "secondary" effects when cultured lobsters reproduce once. The simulation model was also employed to analyse possible biological responses to stock management restrictions such as a spring-fishery ban and an increase in MLS of 2 cm. For these results we refer to Borthen *et al.* (1999).

Two distinct economic perspectives were evaluated:

Public – Cultivation procedures along with releases are publicly managed. Harvesting can be organized either in terms of free access to the fishermen or by allocating limited access, if necessary with a fee;

Private – The releases are organized as private enterprises, with exclusive rights to harvest.

If the releases were privately run, approximately 25 percent would have to be recaptured to cover the costs of inputs and capital. Preliminary estimates at Kvitsøy indicate that 14 percent of the first release group in 1990 can potentially be recaptured, while the other release groups are in the process of recruiting to catchable sizes. The estimates can only be confirmed when all groups have reached catchable sizes. There are indications that predation pressure is particularly high during a brief period just after release, and several suggestions have been made as to how to protect the juveniles against predation. However, in large-scale releases these methods might prove too expensive. If the releases are in the public sector their socio-economic value depends on the value of recaptures of cultured lobsters, the value of recaptures from the next generations (offspring), and the value of the increased or "saved" lobster stock in the situation when the stock was very low before the enhancements started. Preliminary estimates show that an improvement in catch from the second generation can be of the same order as the gain from the first (14 percent + 14 percent), if overall recruitment increases in proportion with the increase in the spawning stock. This assumption has not so far been proven and is still unresolved. A substantial increase in the reproductive potential of, and possibly also recruitment to, the enhanced lobster population has been suggested on the basis of information about the frequencies of berried females of cultured origin in the landings supplied with fecundity data.

Moksness *et al.* (1998) applied a net-present value approach in their analysis based on data from the large-scale release experiments described in this paper, though in an earlier phase. They concluded that sea-ranching lobster would be viable if juvenile costs could be reduced to 6.6 NKr or US$0.85 (exchange rate on 1 September 1999) and if 15 percent of the cultured lobsters were recaptured. LOBST.ECO is more complex and goes one step further by including first-generation offspring. Given the information available from Kvitsøy this approach is more in accordance with reality. Hilborn (1998) evaluated the release experiment in the United Kingdom of the United Kingdom of Great Britain and Northern Ireland on the basis of information obtained from Addison and Bannister (1994) and concluded that with recovery rates between one and two percent this programme was far from economically viable. He did not indicate which recapture percentages would make these release experiments viable.

The lobster hatchery at Kyrksæterøra in mid-Norway closed several years ago, but a Norwegian company, Norsk Hummer AS, plans to build a new large-scale hatchery at Tjeldbergodden, also in mid-Norway. The annual capacity is estimated to be 1.2 – 2.4 million juveniles, and potential customer groups include sea-ranching enterprises (public, semi-public or private) in Norway and abroad, aquaria and, in the long run possibly also intensive cultivation companies. Where the last group is concerned, cannibalism is believed to be the major obstacle to further development. It is believed that each young lobster needs separate compartments, which is very demanding of space and human resources as well as being costly. Preliminary experiments with communal rearing performed at a local hatchery at Kvitsøy in 1998 and 1999 have given promising results as regard to survival, growth and density (Jørstad *et al.*, 2001). These experiments will continue aiming to produce juveniles for release purposes as well as lobsters for consumption. With good results one may expect to see lower prices that would improve the financial results in both sea ranching and intensive lobster farming.

## Associated management strategies

In 1998 a new pilot project commenced at Kvitsøy with the aim of evaluating the feasibility of a ban on landing berried females. Local fishermen at Kvitsøy and the Directorate of Fisheries in Rogaland took the initiative, but IMR is also involved. All berried females, whether wild or cultured, are currently bought from fishermen, and when the fishing season is over these females are released at particular sites around the islands. The idea is to see if this can contribute to an overall increase in reproductive potential and strengthen recruitment on a long-term basis. The local police force is also involved to reduce illegal fishing that peaks during the summer. The experience is without doubt very positive. The fishermen are eager to deliver berried females, and they say that efforts to combat illegal fishing are crucial for the stock.

In a depleted local lobster stock such as the one at Kvitsøy, heavy fishing pressure on cultured lobsters when they reach MLS will only result in a short-term increase in harvest. This implies that annual releases must continue to maintain harvesting levels. Clearly, a more sustainable strategy should include approaches that aim to restore the local stock to previous levels of recruitment, and this will only be possible with the introduction of new approaches to management. In that respect the need for cultivation projects can be regarded more as a temporary activity which can be reduced when stocks reaches an acceptable level.

# Atlantic cod *(Gadus morhua)*

## REVIEW OF FISHERY

The Atlantic cod has a wide distribution and is found on both side of the Atlantic Ocean, and the different stocks have distinct life history characteristics and migration patterns (Jakobsson *et al.*, 1994). Atlantic cod captured on the Norwegian coast are separated into Northeast Arctic cod and coastal cod. The Northeast Arctic cod is a large stock that makes long spawning migrations from its feeding areas in the Barents Sea to the spawning grounds at Lofoten and along the Norwegian coast (Bergstad *et al.*, 1987). Coastal cod, found along the entire coast, are much fewer in numbers and are mainly stationary (Svåsand and Kristiansen 1990). The two groups can be distinguished by both meristic and genetic characters (see references in Svåsand *et al.*, 1996).

Coastal cod were used for the releases in Norway. Catch statistics are available for coastal cod for the area north of 62° N for 1985–97 (Figure 8a), and for the area south of 62° N for 1977–98 (Figure 8b). Whereas catches in the northern part of Norway varied between 25 000 to 75 000 tonnes, registered catches in the southern part were less than one tenth of that quantity. Even taking into account that a large part of the total catches in the southern part of Norway probably are taken by sports fishermen, it must be concluded that total quantity of coastal cod in this area is small. The increasing interest in cod stock enhancement in the late 1980s coincided with both small catches of coastal cod and a crisis in the fishery for the Northeast Arctic cod stock. For fishermen and the fishing industry the latter stock was of greatest importance, and the total catch of Northeast Arctic cod fell to a minimum level in 1990, with total catches of only 187 000 tonnes in 1990, of which only 89 000 tonnes were captured in the Norwegian fishery (Anon., 1999).

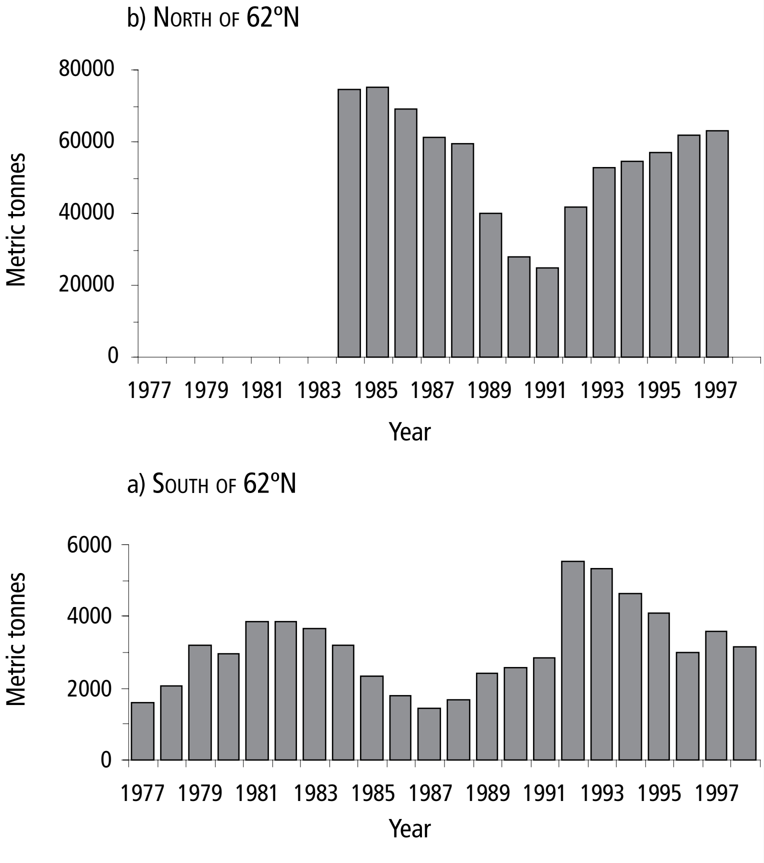
## REVIEW OF PREVIOUS CULTIVATION PROJECTS

In 1864, G.O. Sars discovered that cod has pelagic eggs and he managed to hatch the eggs (Sars, 1879). This made marine stock enhancement possible. Captain G.M. Dannevig, who founded the Flødevigen Hatchery in 1882 followed up Sars' findings and released the first larvae in 1884. Parallel activities were initiated in the United States and Canada (Shelbourne 1964, Solemdal *et al.*, 1984). During the final quarter of the nineteenth century, the development of steam-powered fishing vessels greatly increased fishing power in the North Atlantic fisheries, and both fishermen and politicians soon became concerned about overfishing (Kirk, 1987). Artificial production and release of cod larvae were stated as a means of solving this problem, and the hatchery boom continued for nearly 90 years, mainly in Norway and the the United States. The hatchery period has already been thoroughly described and discussed by Shelbourne (1964) and Solemdal *et al.* (1984).

The last releases were conducted at Flødevigen in 1971 (Solemdal *et al.*, 1984), and a century of cod larvae releases were stopped without any definite evidence of benefit (Tveite, 1971). Later experimental releases of genetically marked yolk-sac larvae have shown that the potential benefits of releasing yolk sac larva are actually very small (Kristiansen *et al.*, 1997).

In Norway releases of cod were re-established on a small scale in the mid-1970s and on a large scale from the mid-1980s, but this time with larger more viable cod juveniles (>10 cm). In 1985 the Research Council of Norway initiated an interdisciplinary research programme on sea ranching of cod (Cod in Fjords) with experiments in several fjords along the coast (Svåsand, 1998). This programme was further scaled up in 1990 when the Norwegian government decided to establish a programme for the development and encouragement of sea ranching (Norwegian acronym: PUSH). The main aims of the new programme were to develop full-scale production of cod juveniles, techniques for mass marking, and to design and conduct large-scale release experiments on the Norwegian coast, in conjunction with extensive field studies aimed at clarifying the potential for profitable sea ranching. A further aim was to determine whether releases of juvenile cod could even out the natural fluctuations in recruitment in cod stock and thereby stabilise the fisheries.

FIGURE 8. Catch of coastal cod along the Norwegian coast.
a) Catch in the area north of 62°N (Berg, Eriksen and Eliassen, 1998), and b) catch in the area south of 62°N (extract of data from Directorate of Fisheries; T. Jakobsen (personal communication, 2000), Institute of Marine Research). The catch statistics only cover catches from registered fishermen




## METHODOLOGY OF SEA RANCHING

### Broodstock selection and management

For the main releases, the broodstocks used for production originated from wild fish collected from the release regions. Both wild captured cod and offspring of wild fish were used as broodstock. However, no breeding programmes have been undertaken so far.

County veterinary health regulations require captured wild fish to have a health certificate before they may be transported to the production site in order to ensure that the broodstock is healthy, and to prevent the spread of pathogens. Similar procedures are required for the transport of fish from one farm to another, and for juvenile fish before release.

Cod readily spawn in captivity, and both spawning pens and spawning tanks were used to produce fertilised eggs. A female cod in good condition can produce about one litre of eggs per kilogram body weight during the spawning season (Holm *et al.*, 1991). In Norway cod spawn from late February to April. After spawning the fertilised eggs are transferred to a hatchery where they hatch after two to three weeks depending on the temperature. Mortality during the hatching period is around 50 percent, and 200 000 to 300 000 larvae normally survive from each litre incubated. However, large variations are found.

The newly hatched larvae are transferred to different types rearing facilities, such as large seawater enclosures (Figure 9), plastic bags or tanks where they are startfed on live plankton, mainly wild. In some cases cultured algae, rotifers and Artemia were also supplied (Anon., 1995). Semi-natural systems have several drawbacks. The main bottleneck is that production is based on the natural production of plankton, which varies according to seasonal and local variations caused by changes in wind directions and other parameters. Toxic algae or pathogens in the surrounding waters can also influence an open system.

On the other hand, we know that reared fish ought to be as natural as possible in order to ensure a high survival rate after release. The development of phenotype and behaviour is influenced by genetic characteristics and environmental parameters (Svåsand *et al.*, 1998b). It is therefore no surprise that cod reared in a natural systems look like wild cod (similar phenotype), and it may be concluded that pond-reared cod are quite fit for release into the wild.

### Tagging method and release strategy

Efficient tagging methods had to be developed before the effects of fish released could be evaluated. For the releases in Norway several types of external tags (T-tags, Figure 10), chemical marks (oxytetracycline and alizarin complexone) and genetic marks (rare genotypes) were used depending on the purpose of the releases. Further details are given in Otterå *et al.* (1998), Svåsand (1998) and Svåsand *et al.* (1998a, b). Use

FIGURE 9. Parisvatnet – the main location for production of juvenile cod in Western Norway. The production unit is a field station run by the Institute of Marine Research in Bergen. The right-hand photograph shows the seawater enclosure (50 000 $m^2$, 270 000 $m^3$). When the cod fry reach a size of about 1 g a dip net is used to collect the fry from the enclosure (left)

FIGURE 10. Use of T-tags was the main external tagging method used on cod in Norway. These tags can be used on cod larger than 14–15 cm

of internal marks requires fishing surveys because these marks are not visible on the outside of the fish. The advantages of these marks are that they are inexpensive, have high tag retention and are easy to apply on large groups of fish. To study migration and when information from fishers is needed, T-tags (Floy anchor tags and T-bar tags) were used. These tags can be used on fish larger than 14–15 cm. Otterå *et al.* (1998) provide further details on tagging cod with anchor tags. In most cases the cod were transferred from the rearing unit to the release area by well boat or in tanks in a small boat. Fresh seawater or $O_2$ were supplied as necessary. At the release sites the juveniles were released into shallow water. During the release programme different release strategies were tried, and the effects of acclimatisation were tested. The mean sizes at released varied between 8–41 cm (Svåsand *et al.*, 1998a).

### Management of the recapture phase; ecosystem analysis

All released fish were tagged or marked. A recapture programme followed up the main releases, and extensive ecosystems analyses were carried out in two of the release areas (Masfjorden/Øygarden) in western Norway and Stålvikbotn, Ullsfjord and Sørfjord in Troms (Svåsand *et al.*, 1998a).

In order to obtain information about recaptured fish from fishermen and sports fishers, the release programme was advertised in local newspapers, and pamphlets and registration forms were sent to local households and placed in post offices and groceries in the release area. A reward of 25 NKr was paid for each returned tag.

### Genetic monitoring

Genetic studies using haemoglobin and five enzymes; LDH, GPI, PGM, GPD and IDH, were incorporated in the different releases in western Norway, and several aspects were studied (Jørstad *et al.*, 1994, Jørstad *et al.*, 1999, Svåsand *et al.*, 1998a). Besides genetic monitoring to detect any unwanted genetic changes, genetic marking was used to distinguish released fish from wild cod. More than 280 000 genetically marked juvenile cod (homozygous for a rare allele; GPI-1*30). were released in Masfjorden and Øygarden, western Norway. Genetically tagged yolk-sac larvae (18 million) were released in Heimarkpollen, Austevoll, south of Bergen in 1995 (Kristiansen *et al.*, 1997) and genetic analyses were later used to detect released fish.

## EVALUATION PROGRAMME

The cod stock enhancement during the PUSH programme was conducted in the following main areas: Austevoll, Øygarden, Masfjorden in Western Norway, Ytre Namdal in mid-Norway, and Vestfjorden and Troms in Northern Norway, and a total of 720 000 reared cod (mainly 0 and 1 groups) were tagged and released between 1990 and 1996 (Figure 11). Several of these releases were prolongations of earlier enhancement programmes, and a total of 1 million juvenile cod have been released on the Norwegian coast since 1977 (Svåsand *et al.*, 1998a).

The following sections summarise the principal results and conclusions of sea ranching cod during the PUSH programme and are based primarily on Svåsand (1998) and the results reported in the final report to the Research Council of Norway (Svåsand *et al.*, 1998a). A more comprehensive review has recently been published in a primary journal (Svåsand *et al.*, 2000).

### Sea-ranching goals

According to Svåsand *et al.* (1998a) the principal aims of the programme were to develop full-scale production of cod juveniles and techniques for mass marking, and to design and conduct large-scale release experiments on the Norwegian coast, associated with extensive field studies to identify the potential for profitable sea ranching.

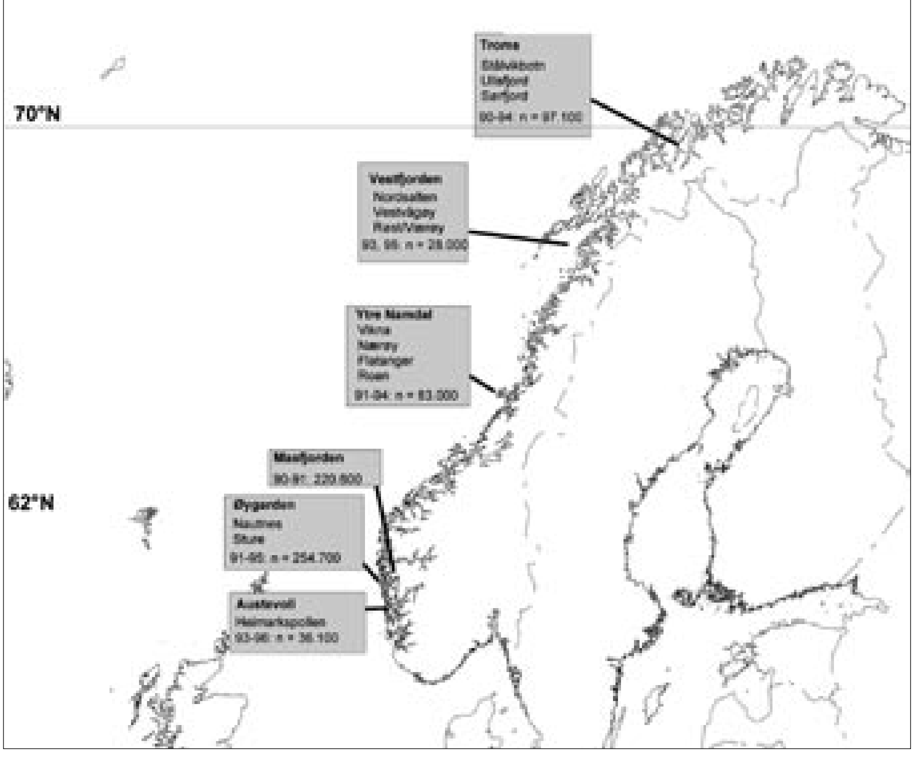
## MAIN RESULTS AND CONCLUSIONS

### Production

The production methods were further developed during the PUSH programme, and a total of nine projects produced 1.2 million cod fry in the period 1990 to 1995. Sufficient numbers of juveniles were tagged and released to test the main aims of the programme (Svåsand *et al.*, 1998a, 2000, Figure 11).

Exposure to an artificial environment during ontogeny might affect both phenotype and behaviour, and thereby also affect survival rates after release. Few differences were found between reared and wild cod after release, and this was attributed to the use

FIGURE 11. Map showing releases of reared Atlantic cod in Norway in the period 1990–1996 (based on data from Svåsand *et al.*, 1998a)



of a semi-natural rearing environment. However, the reared cod needed some weeks after release to acclimatise to the wild environment, and it was also clear that the time in the artificial rearing environment was of some importance. (For further discussion see Svåsand *et al.*, 1998a, 1998b, 2000).

### Genetic monitoring

Apart from the genetically marked fish, the results show few genetic differences between wild and released fish in the same area. In some cases the unexpected frequencies of genotypes found could be attributed to genetic drift possible caused by an inadequate number of fish in the spawning pens. However, these conclusions are based on a small part of the cod's genome. For further details and discussion, see Jørstad *et al.* (1999).

### Migration

Most of the released cod were recaptured in the vicinity of the site of release. Of more than 7 000 recaptures more than 70 and 90 percent were taken less than 5 and 10 km respectively from the place of release. However, both geographical variation and increased dispersion with size were found (Svåsand *et al.*, 2000).

### Recapture

Large variations were found in the reported recapture rates from the different main release areas in Norway, varying from 0 to 15 percent for cod released as 0 and 1-groups (Figure 12). A general trend was a correlation between size at release and reported recapture rates, but release season also influenced the results.

Natural mortality was high in fish smaller than 20–30 cm (depending on release area). The cod recruited early to the local fishery, especially in southern Norway, and were heavily exploited while they were still small. Thus, most of the recaptures were recaptured as small fish, giving a low recapture biomass, even with relatively high recapture rates. The reported recapture yield was smaller than the released biomass for most of the experimental releases, as illustrated by the releases in Øygarden in western Norway (Figure 13). However, when evaluating the results it is important to

FIGURE 12. Reported recaptures from different size groups of cod released in the main release areas in Norway (drawn from data in Svåsand *et al.*, 1998a)

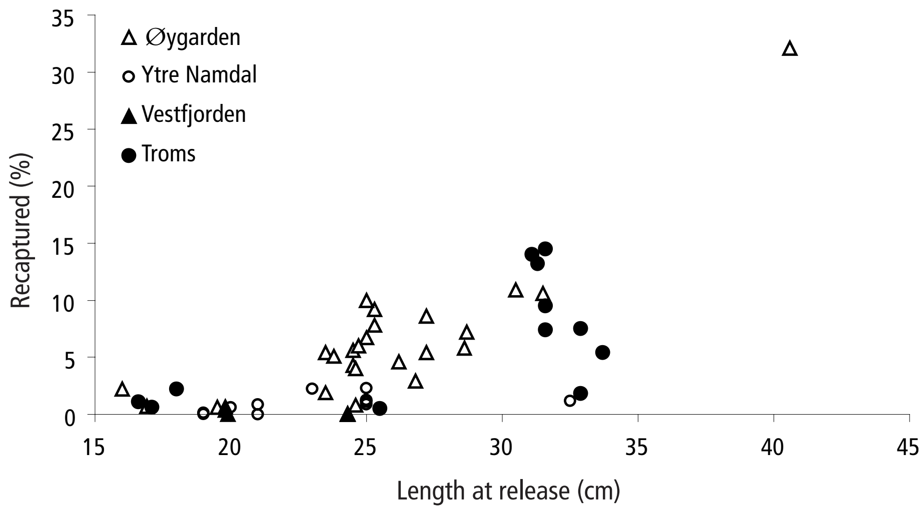
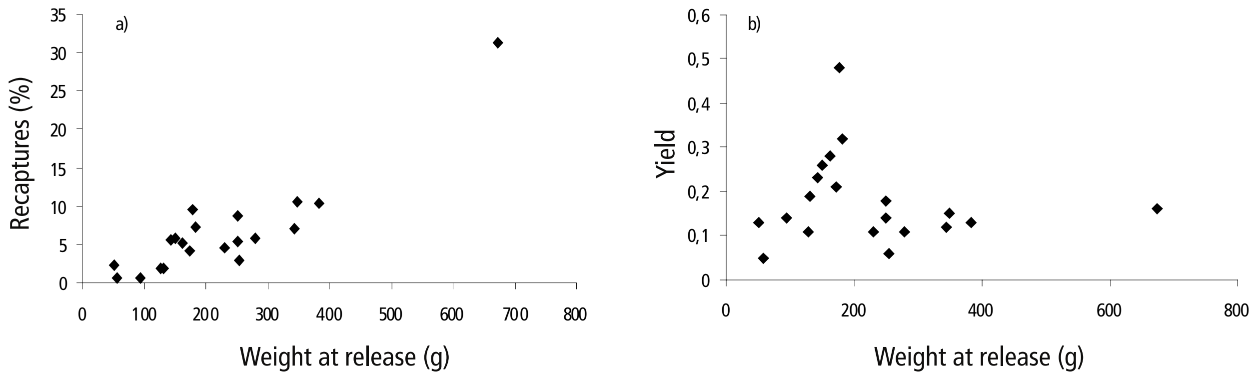


FIGURE 13. Reported recaptures (a) and yield (biomass of recaptured fish/biomass released) (b) from selected releases in Øygarden (drawn from Otterå *et al.*, 1999)




account for unreported recaptures and loss of tags. When 10 percent tag loss (Otterå *et al.*, 1998), and a reporting rate of 41 percent in the Øygarden area (Otterå *et al.*, 1999) are taken into account, nearly all the results were still negative. Similar results were obtained in other areas. Mortality and recapture patterns of released cod are further discussed in Svåsand *et al.* (1998a, 2000) and Kristiansen *et al.* (2000).

## Economic evaluation

Economic profitability could not be obtained with current costs of producing cod juveniles as well as other financial constraints (Svåsand *et al.*, 1998a, 2000). As shown above, the biomass of the recaptured cod was simply too low. Increased fishing pressure due to recreational fishery and tourism on the local fishery resources however, could make releases of cod a method of attraction tourists. Such a concept could involve the release of large (30–40 cm) cod in the vicinity of tourist attractions on the coast or in the fjords. Cod of this size have low natural mortality, and most of the fish would stay close to the release area. Releases of such "large" cod have previously resulted in recapture rates above 50 percent.

There is currently a growing interest in net-pen rearing of Atlantic cod, due to new knowledge about more effective rearing methods, using light to postpone the time for maturity and increased growth, and better prices for cod in Norwegian and European markets. Given the economic constraints of today, and new biological knowledge, interest in Atlantic cod has shifted during the 1990s from stock enhancement to net pen rearing.

## Evaluation of new knowledge

Cod stock management activities in Norway have resulted in a wealth of new information, and the final report from the PUSH-programme (Svåsand *et al.*, 1998a) refers to 13 M.Sc. dissertations, six Ph.D. theses, and more than 60 refereed publications that deal with various aspects of the scientific basis of stock enhancement.

This unique knowledge, which is now published in a refereed journal (Svåsand *et al.*, 2000), will be of importance both for the further development of stock enhancement in Norway and also as a basis for evaluation of marine species stocks in other countries.

**Implication for management**

There have been no changes in the management of coastal cod resources during the programme period. There are minimum size limits for sales of cod; 47 cm north of 64° N, and 30 cm south of this 64° N. For fishing for one's own household there are no size limits, only a limitation in the amount of fishing gear permitted (max. 210 m fishing nets, 300 hooks, and 20 pots or traps). Foreign citizens may take part in sports fishing with hand-held tackle, but may not set out fixed equipment, and they are not allowed to sell their catches. Nor are Atlantic cod included in the new proposal for an Act on sea ranching, as this will deal only with molluscs, crustaceans and echinoderms.

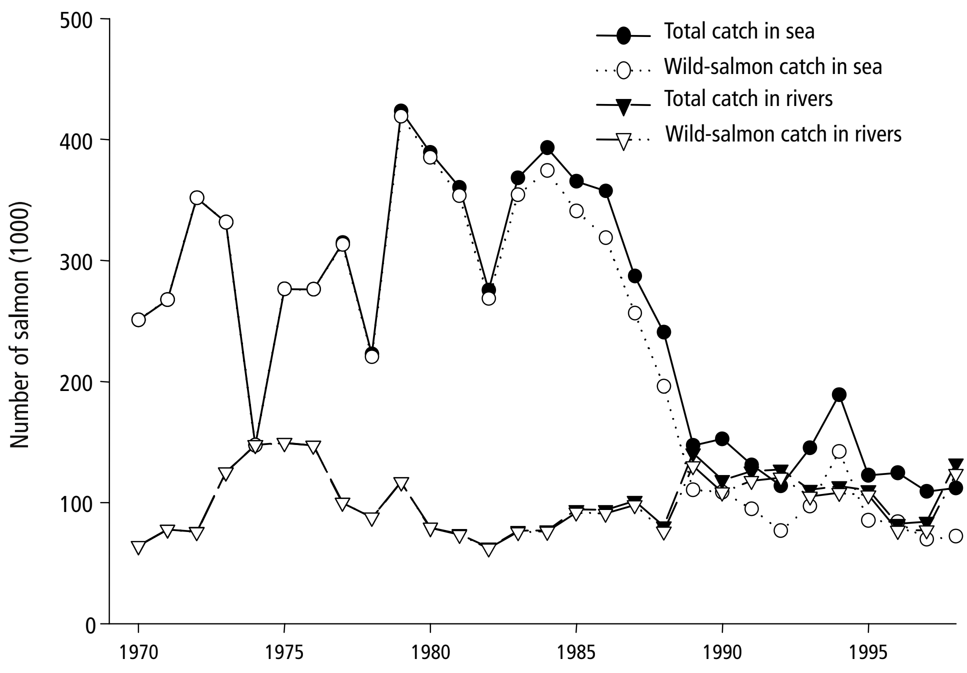
As shown above, a great deal of the new knowledge that has been obtained during the programme is relevant for the future management of coastal cod stocks, as well as for other important coastal resources. It is likely to take some time as well as further treatment of the data before this new information can be incorporated in the management of wild cod stocks.

# Atlantic salmon *(Salmo salar)*

## REVIEW OF FISHERY

Historically, a commercial sea fishery of salmon was established with the introduction of bag-nets towards the end of the nineteenth century. During the 1970s a driftnet

FIGURE 14. Official statistics of Atlantic salmon catches in Norway in 1970–1998. The numbers are corrected for the catch of escaped farmed salmon by including estimates of the sum of both escaped and wild salmon (filled symbols). (Sources: Statistics Norway, Directorate of Nature Management, Norwegian Institute for Nature Research)



fishery developed. Until the ban of this fishery in 1988, the number of salmon caught in the sea was clearly higher than the river catches. During the 1900s sea-catches of wild salmon were comparable to those in rivers (Figure 14). The numbers of salmon caught in rivers has been relatively stable since 1970. However, new regulations and improved salmon management have probably improved the statistics and mask a probable decline in many stocks during this period.

## REVIEW OF PREVIOUS CULTIVATION PROJECTS

In the 1750s Jacobi from Germany was the first to hatch eggs of freshwater fish, but at the same time the Norwegian Jakob Sandungen was apparently carrying out similar experiments (Sømme 1941). Releases of larvae and juveniles expanded in Norway during the 1850s and several hatcheries were built, mostly to produce trout but also for salmon and Arctic char. An important part of this expansion can be traced back to public funding and the establishment of public inspections of the freshwater fishery. The extent of salmon larvae releases increased considerably when an export duty was introduced, and in the 1940s releases of salmon reached the level of trout releases. Between six and seven million salmon larvae were released as opposed to eight million trout. The larvae were released shortly after hatching because it was believed that natural mortality was highest in eggs. The purposes of these releases were to stabilise the stocks, increase the fishery and to introduce fish to lakes that had previously contained few or no fish.

In United States it was common as early as the end of 1800s to produce older juveniles in order to further reduce natural mortality. In the early 1900s most other countries in Europe had adapted this method while in Norway it did not become common practice until the 1970s. The most common strategy was and still is to release fish that have hatched in the spring, fed for a few months and then released during the summer. The number of smolts produced increased from about 250 000 in 1970 to one million at the end of the 1980s.

In Norway most of the stocking programmes took place in rivers and watercourses that already contained natural and wild salmon populations. In other countries the focus was on other kinds of releases, localities and purposes. In Iceland, for example, a research station was build in the early 1960s to produce salmon for release into small rivers or watercourses that did not already have natural wild salmon populations. In the 1980s, a "sea ranching stock" was built up to produce smolts for commercial release projects. Recapture rates were high at the release locations, frequently above 5 percent during the 1980s, however recaptures decreases for unknown reasons in the 1990s. Prices also fell at the same time and today the Icelandic fish-stocking industry has closed down.

In Norway work was done with tagged salmon smolts, which were released to study smolt behaviour, migration and adult returns. A research station that was operational in the River Imsa since the early eighties compared the performance of wild and cultured smolts in a number of experiments (Jonsson and Heggberget, 1993). Knowledge of freshwater rearing practises and smoltification was being accumulated in parallel with the buildup of a substantial farming industry in Norway. There was political will to stimulate the development of sea ranching in coastal areas due to the ban of the driftnetting fishery in 1988. This fishery, which was an important component of fishermen's income in many coastal communities, was responsible for most of the catches in the sea until 1988 (see Figure 14).

## METHODOLOGY OF SALMON SEA RANCHING

The following section summarises the principal results and conclusions from the salmon sea ranching projects during the PUSH programme, and is primarily based upon preliminary results reported in the final report to the Research Council of Norway (Skilbrei *et al.*, 1998).

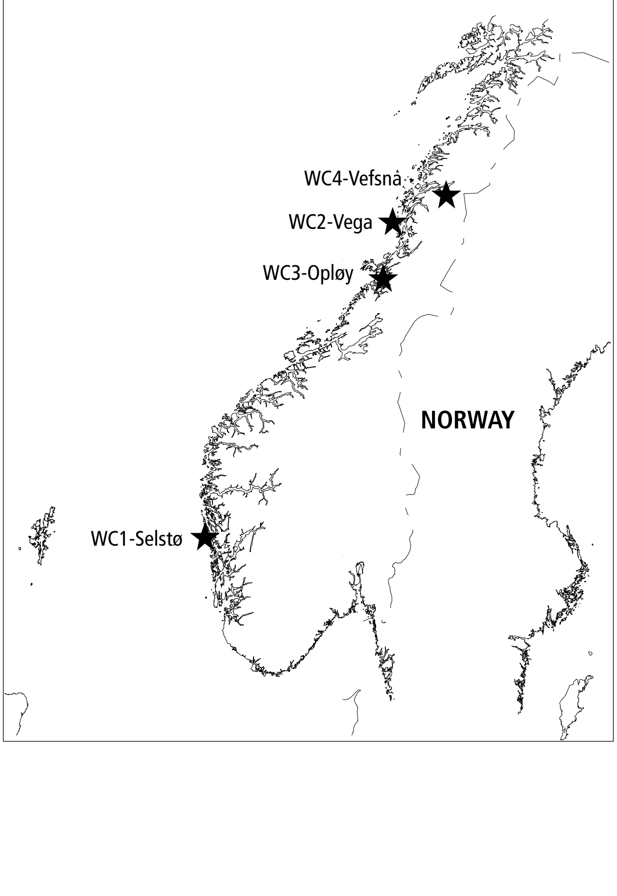
### Sea ranching models and release sites

Four different release sites were chosen for sea ranching Atlantic salmon. The intention was to test different sea ranching strategies and to compare localities that differed with respect to size of the watercourse and distance to open sea. The projects mostly released smolts, but yolk-sac fry were released in one of the projects. For the sake of simplicity, the projects are termed according to the size of the watercourse at each location. They are called WC1, WC2, WC3 and WC4, where WC1 denotes the smallest watercourse, and WC4 the largest.

#### *Project WC1*

Smolts were released from net pens into a small marine bay located on the outer coast of western Norway (see Figure 15). A small watercourse of 1.5 km$^2$ basin drains to the bay. Most of the freshwater runs through a small hatchery close to the bay in which the smolts were kept prior to release. The watercourse (a brook) was much to small to support a wild salmon stock, and it could not be entered by returning adults that were caught in the bay by gillnets. A monitoring programme was developed to estimate catches of sea-ranched salmon by the nearby bag-net coastal fishery for migrating salmon. Between 40 000 and 55 000 smolts were released annually for three successive years, 1992–1994.

FIGURE 15. Location of the four release projects with Atlantic salmon; WC1 in the Selstø Bay on the outermost coast of western Norway, WC2 at the island of Vega off the coast of mid-Norway, WC3 at the river mouth of River Opløy at the head of the Opløy fiord and WC4 in the River Vefsna




In WC1 the primary goal was to develop methods for sea ranching from a small watercourse located on the coast. The rationale was that such locations maximise the distance to, and hopefully minimise the interactions with, natural populations that are usually to be found in fjord areas. In addition, survival was expected to be high as there are a number of species that prey on the wild smolts from the time when they leave the river mouth and migrate through the fjord region. Emphasis was put on detailed studies of stock and family variations, release methods and geographical distribution of adult catches.

***Project WC2***

This project was located to the island of Vega, close to the outlet of a river draining a basin of approximately 20 $km^2$. A small grilse stock spawns in the river. The smolts were transferred from a mainland hatchery to net pens close to the river mouth prior to releases. After a small release of 7 400 smolts in 1991, 74–136 000 smolts were released every year from 1992 to 1995 except in 1994, when most of the smolts were killed as the result of a technical accident. Anglers in the river caught some returning adults, but most were caught in bag-nets and gillnets in the sea close to the mouth of the river. Project WC2 was also located on the outer coast (an island), but its emphasis was on releasing large numbers of smolts in order to simulate a situation that would resemble a commercial ranching operation. One reason for this approach was the explicitly stated political goal of identifying new sources of income in coastal regions after the ban of the coastal driftnet fishery for salmon in 1989. In addition, promising results had been obtained from similar project in Iceland during the 1980s.

***Project WC3***

The project was located on the Opløy River in the head of the Opløy Fjord in mid-Norway (Figure 14). The smolts were released in the river mouth close to the sea or from net pens in the estuary of the river. Salmon are prevented from entering the main course of the river by a hydroelectric power plant. Returning salmon were caught by a combination of bag-nets in the inner part of the fjord, angling in the estuary and lower 300 m of the river and catches in a trap in the lowest part of the river. From 1989 to 1996 a total of 558 000 smolts were released. The Opløy River is large enough to sustain a sports fishery for returning salmon in the river mouth. By including the recreational angling approach it was assumed that anglers would be willing to pay a higher price per fish compared with commercial market prices for salmon, thereby increasing the profitability of the project. The project was therefore organized in cooperation with local interests that administrated the fishery; sale of fishing licenses, accommodation etc. An intensive tagging programme was implemented in order to gain basic knowledge relevant to the further development of the project, for example to provide an economic analysis with data for estimating the costs and benefits of this sea-ranching model.

***Project WC4***

Unlike the other projects, WC4 was located in a large river that supports a wild salmon population; the River Vefsna. The project compared two different strategies; 1) releases of unfed fry in the upper tributaries of the river Vefsna that are not naturally reached by salmon, and 2) releases of smolts in the lower reaches of the river. In small lakes and rivers in the three upper tributaries approximately 150 000 fry were released every year, and traps for migrating smolts were built to measure the production potential in these areas. Between 1992 and 1995, a total of 58 310 Carlin-tagged one- and two-year-old hatchery-reared smolts were released, and in 1987–1995 a total of 10 512 wild smolts were captured and tagged for comparison.

The main goals of project WC4 were to study the potential for sea ranching and to reinforce the River Vefsna stock. Vefsna used to be an important salmon river, but production has dropped dramatically due to the introduction of the salmon parasite *Gyrodactylus salaris*. In that respect, the releases of fry in the upper tributaries are comparable to an enhancement programme. One important objective for the releases of hatchery-reared smolts in the main river was to compare the survival rate of these fish with the adult returns of Carlin-tagged wild smolts (originating from the fry releases) and with the hatchery smolts of the same hatchery stock released on the outer coast in project WC2.

## BROODSTOCK SELECTION

The broodstock were taken from the same region as the intended release area, since salmon stocks from different regions may have different migration patterns, feeding area and ecological preferences. In this way, fish that stray can be expected to enter nearby rivers and will then belong to the gene pool of that area. Brood fish were also selected according to background information regarding the age and size of returning wild fish, since such factors influence the outcome of sea-ranching operations.

For the three stocking projects in mid-Norway (WC2, WC3 and WC4) multi-sea-winter stocks were chosen because large salmon are more valuable than the grilse component returning after one winter in sea. In project WC3 the size of the brood fish varied from 7 to 12.5 kg. The size of the brood fish in project WC2 and WC4 was from 6 to 7 kg. As mortality is expected to increase with the duration of the stay in the sea, several stocks were tested at the southernmost release site, project WC1. A typical grilse stock in which the adults rarely reach weights above 2 kg, a stock composed of both grilse and multi-sea-winter salmon (1.5–10 kg) and finally a stock known for its large size, were selected. In the last case, females were between 5 and 12 kg, while males ranged from 1.5 to 13 kg.

In project WC3 the brood fish were caught in bag nets in the sea close to the river mouth of the large River Namsen in midsummer and kept in net pens until late September when they were transferred to hatchery tanks supplied with running freshwater and stripped in late October. In the other projects brood fish were sampled from the spawning grounds from September to November.

### Rearing of young fish

Except for the releases of unfed fry in WC4, smolts were produced according to standard production regimes of commercial hatcheries (see e.g. Edwards 1987). In WC3, smolts were bought from a commercial hatchery. In WC2 and WC4 a hatchery was taken over to produce smolts for releases purposes only. In WC1 the first generation of smolts was produced at the hatchery at the release site, operated by the Institute of Marine Research, while the following two year-classes were produced by a commercial hatchery. In order to study family groups, they were kept separated in relatively small tanks of 1×1 metre, during the early development stages, and transferred progressively to larger tanks (2 to 8 m diameter) when they had grown large enough to be tagged.

### Tagging method

Several tagging methods were employed; microtags, visible implant tags and adipose fin-clipping, Carlin tags were used most frequently. This external tag has been utilised in salmon research in Norway for several decades and is therefore familiar to the public; hence the likelihood of receiving tags from the sea-fishery for migrating salmon and from anglers in rivers, especially when the fish are caught far from the release site, is higher for this tag. However, attaching the tag to the fish by two thin metal wires just below the dorsal fin may be harmful and probably increases post-release mortality. This problem is probably most serious when tagging 1+ smolts, as they are usually smaller than 2+ smolts. Unreported tags contribute to bias survival rates. Comparisons between recaptures of adipose fin-clipped and Carlin-tagged adults at the release sites in WC1 and WC2 indicate that 1+ return of Carlin-tagged fish are approximately 30 percent lower. For individually tagged cod released in the same geographical region as WC1 smolts, Kristiansen *et al.* (2000) estimated that 50 percent of recaptured tags were not reported by fishers. A further factor is that released cultured fish that stray normally enter rivers so late in the season that the sports fishery is closed in most rivers. Thus, the probability of receiving tags from these fish may be low. When all factors are taken into account, a doubling of the reported recaptures may be a fair approximation for estimating total returns (Hansen 1981, Hansen 1986, Isakson and Bergman 1978). In the following paragraphs reported tag recoveries are presented, except for the data shown in Figure 18.

Different proportions of the released smolt groups were tagged with Carlin tags; between 8 and 30 percent of the fish in WC1 and WC2 and from 50 to 100 percent in WC3 and WC4, partly depending on the numbers released.

### Release strategies

Because of differences in the aims and organisation of the projects, practical restrictions and different physical and geographical conditions at the release sites, it was necessary to develop a range of release strategies.

During smoltification and silvering the young salmon develop the ability to osmoregulate in full-strength seawater (Hoar 1976). The process is synchronised by photoperiod and partly entrained by temperature (Folmar and Dickhoff 1980). In sea ranching it is important to find the "optimal" release period, and technique during the parr-smolt transformation to maximise post-release survival, as the transfer from fresh- to seawater may be critical. In WC4 the smolts were released upstream in the river Vefsna and were thus given the opportunity to enter seawater voluntarily. The connection with freshwater was weaker in the other projects. Smolts were released not far upstream of the river mouth, directly into the estuary or transferred to net pens in the sea. Experiments on remote marine releases were also performed. Net pens were towed from the head of the river mouth, where the release site was located, to the outer region of the fjord before the smolts were released (WC3). Acclimatisation to seawater through periods in net pens in seawater prior to release was chosen in both WC1 and WC2, but in the course of the programme methods were developed to facilitate adaptation to seawater by creating artificial salinity gradients resembling a river estuary. This was done by spreading a floating 3 m deep tarpaulin across the release bay to accumulate the surface freshwater runoff in the inner part of the bay in WC1 (Skilbrei *et al.* 1994b). Similar conditions were established in WC2 when freshwater was delivered by pipeline to net pens that were closely surrounded by a 3 m deep tarpaulin to establish a fresh-/brackish water layer, 1 to 2 m deep.

### Genetic monitoring

Preservation of the genetic variation in natural stocks is important for continued evolution (Ryman, 1981). Aquaculture activities, such as stock enhancement, aquaculture and artificial breeding may have impacts on native gene pools if sea-ranched or escaped farmed salmon stray, because the hatchery environment represents new conditions which can induce drift in the gene pool. For this reason, an expert group recommended developing a research programme during the PUSH-programme to study the potential impact of sea ranching on wild stocks (Mork, 1989). Ten years later there is still little information that documents the genetic structure of salmon populations in Norway. Jørstad *et al.* (1999) offers an overview and evaluation of the genetic aspect of the PUSH programme.

Studies of genetic variation in a wild stock were only performed as part of project WC1. The main focus was on quantitative traits. Family groups of the three stocks from which the brood fish were collected and compared with respect to factors as growth rates, smolt sizes, size at maturity and return rates. During the programme substantial genetic differentiation was observed between the stocks for the allelic frequencies of six polymorphic enzymes investigated (Skilbrei and Skaala, 1997). In addition, a study was designed specifically to study the genetic and ecological consequences of immigration from a ranched to a wild population. In addition to smolts produced in WC1, smolts from the same river's stocks that possessed a genetic marker (found among the wild parents after screening for *polymorphe allozyme loci*) were transported and released in the small river River Øyre. Unfortunately, due to financial constraints and poor survival of the released fish, the gene pulse was too weak to be quantified during the programme.

The recommendations by Mork (1989) that broodstock of local or regional origin should be used were followed in all projects. Knowledge of the genetic variation in wild populations and potential genetic interactions with wild stocks is needed to perform risk assessments (Busack and Currens, 1995) and to develop sustainable ranching (Anon., 1993). The programme did not deal with this aspect. However, the fact that straying rates and the geographical distribution of the strayers differed between projects, and seemed to be influenced by rearing and release methods, offers hints as to how future sea-ranching projects should be planned.

### Fish health management

After brood fish collection and fertilisation of the eggs, the eggs from each female were kept separately in a quarantine section of the hatchery while the brood fish were screened for diseases. Some groups were destroyed due to *furunculosis*. The fish were kept under veterinary control during the culture phase in freshwater, and more intensive screening for pathogens were carried out before transport and release.

## EVALUATION PROGRAMME

### Goals for sea ranching

The basic objectives of all four projects were to find methods of increasing our basic knowledge of sea ranching of Atlantic salmon, especially regarding practical solutions employed in producing, releasing and catching returning adult salmon. The primary goal was to identify sources of variation in survival in order to incorporate these findings into the design of the projects. While the main focus was to increase adult returns, it was also an important issue (WC3) to incorporate the biological findings in a sea-ranching model based on a recreational sports fishery that was organized in a local enterprise. The programme also aimed to compare the different models for sea ranching represented by the projects. A basic target was to minimise straying in order to reduce interaction with wild salmon populations.

### Quality of smolts

Opportunities for growth during the freshwater phase differed between the projects, resulting in high proportions of two-year-old smolts (2+ smolts) in WC3 and WC4.

In WC1, more than 50 percent of the fish reached smolt size after one year, and potential 2+ smolts were not used for releases. Wide variations in freshwater growth rates resulted in different proportions of 1+ smolts and clear size differences between smolts, between family groups and between stocks (Skilbrei *et al.* 1998). The outcome of the intensive part of sea ranching in freshwater is therefore difficult to forecast, compared with commercial culture of salmon, because the offspring of wild parents have not been selected for improved performance for several generations as has been the case for the cultured Norwegian strains. For these reasons, the production of smolts for sea-ranching purposes will be more expensive than growing cultured stocks for cage rearing. In addition to physical factors determining the growth rate (as temperature), the cost of the smolts will depend on the inherited potential for freshwater growth of the stock in question, implying that the choice of stock is an important first step when planning sea-ranching projects.

The releases of unfed fry in two upper tributaries in Vefsna (WC4) resulted in yearly smolt runs that ranged from 200 to more than 4 000 individuals. Over the years, production was equivalent to 1.0 and 1.1 smolt/100 m2 in the two tributaries. It was concluded that growth rate and survival were high compared with rivers naturally populated by salmon, but that both factors are reduced if too many fry are released annually. It was supposed that the quality of these smolts is equivalent to that of wild smolts.

The quality of cultured smolts is difficult to measure. During the smoltification process the ability to osmoregulate in full-strength seawater develops. The physiological response to salinity increases and can be measured, but important questions about the behaviour of smolts after release still remain. Our understanding of the role of the rearing environment for the development of the individual is limited, especially when discussing whether, or to what extent, a cultured fish is capable of behaving naturally after being released into the wild (Svåsand *et al.*, 1998b). The smoltification process is timed by environmental cues and is believed to be crucial for survival in the sea, i.e. smolts should be released at an optimal stage of this process. In all projects, smolts were released during a period of several weeks in spring or early summer (May–July) depending on latitude. In WC1 an attempt was made to evaluate the release method by surveying the behaviour of the smolts after release by underwater video. The tendency to organize in rapidly swimming schools was taken as a measure of the preparedness of the smolts to migrate, and then it became clear that migration motivation develops gradually over several weeks as a behavioural part of complex changes associated with smolting (Skilbrei *et al.*, 1994a). In sea ranching operations too early releases may result in increased mortality. For this reason, smolts should be size-graded before release as the development of migration motivation is also size-dependent.

## Adult returns

In both WC1 and WC3, the annual recapture of adults at the release site was approximately one percent of the number of smolts released, i.e. an annual recapture of 300 to 370 individuals in the Selstø Bay and 618 to 1 498 salmon in Opløy. However, a considerable fraction of the fish was recaptured in the vicinity of the release sites (see Contribution of hatchery fish to fishery). The total recapture of Carlin-tagged smolts was somewhat higher in WC1 (Table 3).

Except for a homing of 2 percent of 7 400 smolts released in 1991 into the river mouth at the WC2 release site, the catch at Vega was insignificant compared with numbers released until 1996. Following the 1995 releases 4 400 adults homed to WC2 during the next three years, equivalent to 3.3 percent of the release. The corresponding number was lower for the Carlin-tagged two-year-old smolts (2.2 percent), possibly demonstrating the combined effects of tag loss and higher mortality of tagged fish.

There are two main reasons for the evident improvement of the Vega (WC2) releases. The smolts released in 1995 homed much more successfully than previous year-classes, showing a much more pronounced geographical distribution. In addition, while one year-old smolts dominated the other release years, 97 percent of the 1995 smolts were two year-old smolts. The one year-old smolts of the Vefsna stock performed poorly in both WC2 and WC4 (Table 3). Results from WC4 indicate that such effects may be due to size differences between one and two year-old smolts.

TABLE 3. Adult recaptures as percentage of Carlin-tagged one- (1+) and two-year old smolts (2+)

| Release year | WC1 | | WC2 | | WC3 | | WC4 | |
|---|---|---|---|---|---|---|---|---|
| | 1+ | 2+ | 1+ | 2+ | 1+ | 2+ | 1+ | 2+ |
| 1989 | – | – | – | – | 4.6 | – | – | – |
| 1990 | – | – | – | – | – | 3.3 | – | – |
| 1991 | <0.1* | – | – | – | 0.4 | 0.1 | – | – |
| 1992 | 3.6 | – | 0.4 | 2.9 | 2.3 | 1.5 | – | 3.2 |
| 1993 | 3.9 | – | 0.4 | 2.1 | 1.0 | 2.5 | 0.1 | 0.9 |
| 1994 | – | – | – | – | 0.1 | 1.5 | 1.2 | 1.5 |
| 1995 | – | – | 1.0 | 3.1 | – | 1.8 | – | 0.3 |
| Total | 3.8 | | 0.7 | 3.0 | 1.6 | 1.8 | 0.5 | 1.2 |

*VI–tagged smolts, not included in total.

In general, there was high degree of variability in survival rates operating at various levels; between families, stocks, release sites, age classes, release methods and years. Whereas specific groups showed survival close to 0 percent, the highest scoring groups of WC1, WC2, WC3 and WC4 produced 12.8, 6.4, 5.0 and 3.4 percent tag recoveries, respectively. The genetic origin of the fish was one of the factors that contributed to variations in return rates (Skilbrei and Skaala, 1997), as has also been shown in Icelandic experiments at family level (Jonasson *et al.*, 1997).

In WC1 and WC2, where low freshwater discharges presented potential problems for smolt transfer to seawater, the creation of salinity gradients in the net pens presumably facilitated the parr-smolt transformation by offering the fish salinity alternatives that may have resulted in higher returns and/or improved homing ability in subsequent years (from 1992 in WC1 and from 1995 in WC2). In WC3, towing the net pens to the outer part of the fjord before releasing the smolts decreased avian predation in the fjord and raised survival rates above those of the river-mouth releases (to 6.4 percent).

Information has recently become available to suggest that increased abundance of salmon lice, possibly due to cage rearing of salmon, may reduce the survival of wild salmon. Coincident with the rapid growth of cage rearing in the region where WC1 was located, the size of local wild stocks in this area have declined drastically during the past decade. Studies on migrating wild smolts have shown lethal salmon lice infestation rates on the Norwegian coast (P. Jakobsen, University of Bergen; B. Finstad, Norwegian Institute for Nature Research, personal communication). Very high numbers of lice were also found in Selstø Bay (Skilbrei *et al.*, 1994b), suggesting that the parasite fauna ought to be investigated prior to releases.

Annual variations in return rates in the projects were presumably a consequence of factors mentioned above and large-scale fluctuations in the Norwegian Sea ecosystem. The geographical location of the release site may influence predation, smolt survival, smolt and adult navigation and the ability of the spawning migrating adults to be caught in different ways. It is impossible to fully compare the four release sites with respect to survival of smolts because of differences in release methods, stocks etc.

The effects of releasing unfed fry were measured by Carlin-tagging smolts caught in fish ladders as they were migrating out of the two upper tributaries of the River Vefsna (WC4). A mean survival to the adult stage of 0.9 percent indicates that naturally produced smolts had a return rate between those of cultured 1+ and 2+ smolts (see Table 3). Utilisation of former ”unproductive” areas in the upper tributaries of salmon rivers represents an inexpensive smolt supplement that adds significantly to the natural smolt run and increases adult returns.

### Interaction with natural populations

Sea ranched smolts can interact directly with natural populations if they are released into a river system that supports wild salmon, if they compete with wild salmon during the feeding period in sea and if they stray when they are entering freshwater to spawn. In addition, indirect interaction may be seen if the number of fishing gears increases in response to the releases.

### River releases

Releases of juveniles into a river may represent a major energy input to an ecosystem that is mainly based upon extraneous supplies of organic matter. The consequences are poorly understood, but reduced survival of the wild juveniles may be a result, either due to increased competition and/or because of a build up of predatory stocks (Sægrov and Skilbrei, 1999). A preferable strategy may therefore be, as in WC4, either to release the fish as smolts because they are supposed to leave the river rapidly after release, or to use those tributaries for stocking of unfed fry where salmon are prevented by waterfalls, etc., from spawning.

### Feeding competition

In the Pacific large-scale releases of salmonids may alter the conditions for survival and growth within and between species. In the North Atlantic, the number of salmon feeding is probably very low compared to the situation more than 100 years ago, when many large European rivers were still habitable for salmon. The yearly production of Norwegian smolts heading for the Norwegian Sea is now believed to be as low as approximately 10 million smolts. The abundance of salmon in the North Atlantic is probably far below the carrying capacity for salmon in this area, and it is not likely that the releases of smolts during the PUSH programme, 100 000-200 000 smolts yearly, have influenced this situation.

### Straying

Straying was high in WC1 in comparison with assumed natural straying rates of below 10 percent. Despite the assumed rate of recaptures in rivers (approximately 50 percent of spawning run), the numbers of Carlin tags reported from rivers were comparable to or higher than the recaptures at the release site. However, the rearing environment in the hatchery tanks before release seemed to influence the straying rate. The pre-smolts held under the highest of two water current velocity regimes showed least straying, and the

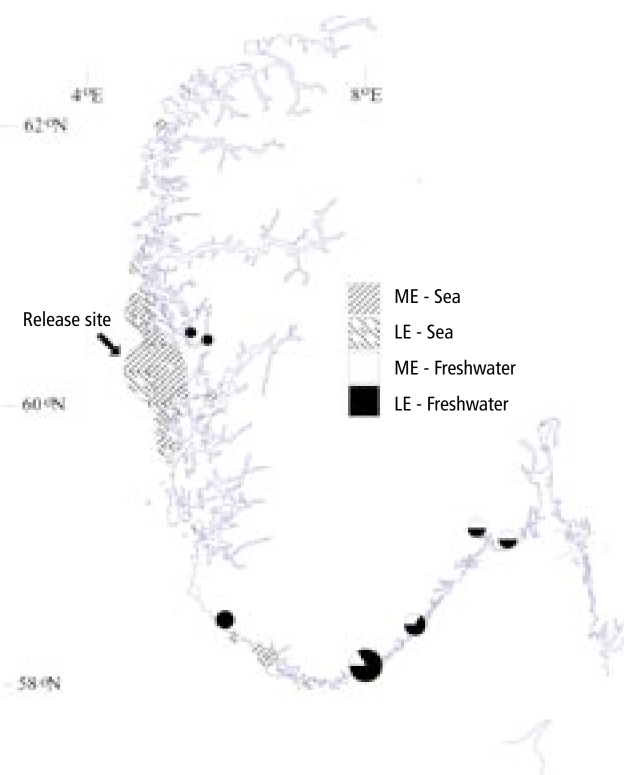



FIGURE 16. Geographical distribution of reports of ME (moderate-exercise groups kept under 1.0–2.0 body lengths/second current velocity prior to releases) and LE (low-exercise groups held in water current velocity of 0.5–1.0 body length/second) Carlin-tagged grilse released as smolts in 1992. Size of pie charts is proportional to the number of individuals, showing from one to 17 salmons. Data from Skilbrei and Holm (1998)

highest homing rate (Figure 16, Skilbrei and Holm, 1998). In the project on the outer coast, with a small watercourse (WC2), straying was low in terms of numbers but relatively high as a percentage when total returns were poor, and low (<5 percent) in 1996 when total returns were high. Releases of smolts of the same origin released in a large river (River Vefsna, WC4) gave high straying, 20–50 percent. In WC3, straying was about 4 percent every year.

In general, there was no relationship between the size of the watercourse and straying rate, or between straying and coastal and fjord/river release sites. Differences in release methods may contribute to an unknown extent to the variation in straying if it is assumed that both the handling of the smolt and their experience during this phase can influence imprinting. Nor can it be ruled out that the probability of straying may be high at specific locations due to interactions between imprinting, local hydrographical conditions, migration routes, etc.

## Fishing effort

It was clearly demonstrated in WC3 that fishing effort increased in response to greater abundance of salmon in the area following releases. Over a period of five years the numbers of gill nets and bag-nets in the Opløy fjord increased by about 100 percent. In the outer part of the fjord wild salmon were more frequent in the catches than ranched salmon. Fishing pressure on wild salmon thus increases when the quantity of reared salmon increases.

## Contribution of hatchery fish to fishery

For the sea-rancher the geographical distribution of the recaptures is of particular interest. If there is a commercial fishery for migrating salmon in the region, and the rancher's exclusive rights are limited to the release site, then the loss of fish may be substantial.

The fishery for adult returns in Norway can be divided into recaptures at the release site, in the commercial bag-net and gillnet fishery for migrating salmon mainly along the coast and in outer fjord regions, and fish that are taken by anglers in rivers (strayers). The reported recaptures at the release site in WC1, 2 and 3 are probably close to true recapture rates, as this fishery was partly or wholly operated by the project staff. For salmon recapture elsewhere, we have to rely principally on the number of Carlin tags reported by fishermen and anglers. These numbers must necessarily be minimum estimates.

### Catch at the release site

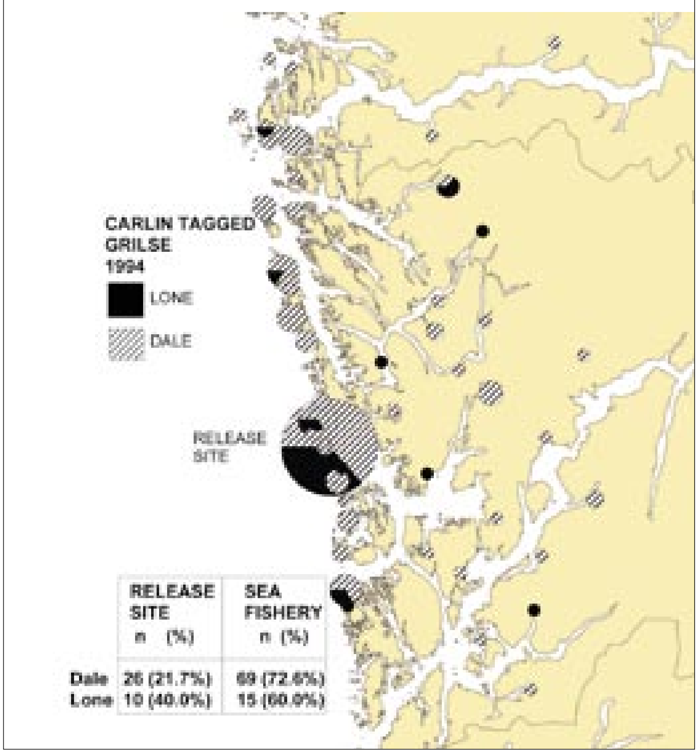
In WC1 the primary goal was to recover tags to study survival, growth rate, etc. of the released groups, and project staff therefore operated the monitoring. This was also done in WC2, which was designed to simulate a commercial sea ranching operation. Bag-nets and gillnets were utilised, with the latter proving to be most effective. One bag-net was used in WC3, but most fish were angled in the estuary of the river Opløy. In WC4 the fish were caught in the traditional sports fishery in the River Vefsna or in a fish ladder. Except in the case of WC4, there had been no fishery for salmon at the release site prior to the sea ranching programme.

### Sea fishery

The contribution of hatchery fish to the sea fishery varied between release sites and year classes. It was generally high in WC1, approximately twice what was caught at the release site (example shown in Figure 16). Most of these fish were caught in the vicinity of the release site. On the basis of catch protocols provided by local fishermen, approximately 10 percent of the catches were sea-ranched salmon. However, a large but unknown percentage of their catch consisted of escaped farmed salmon. Although the number of smolts released annually was relatively low (40 000), it is likely that the releases influenced the catches of sea-run salmon in the region. The contribution to the sea fishery clearly differed between the stocks. Because of size selectivity in the fishing gears, a lower proportion of the typical grilse strain was caught in the sea fishery because they were smaller than the grilse of the other stocks (Figure 17).

In WC2, the percentage of Carlin tags reported by fishermen varied widely; from almost 100 percent in 1994 when return was

FIGURE 17. Map showing local sites of reported Carlin-tagged grilse of the Lone and Dale stocks in 1994, and a table summarizing all reported tags from these two stocks from the release site or sea-fishery. The smallest circles refer to one tag, whereas the largest circle (release site) summarizes 41 tags




| | RELEASE SITE n (%) | SEA FISHERY n (%) |
|---|---|---|
| Dale | 26 (21.7%) | 69 (72.6%) |
| Lone | 10 (40.0%) | 15 (60.0%) |

poor to 20 percent in 1996 when catches at the release site peaked at nearly 80 percent. In both cases, the absolute contribution of these fish to the sea fishery was low. This was also seen in project WC4, which covered the same geographical coastal zone. In WC3 – Opløy – catches at the release site were close to 50 percent of all reported Carlin tags, which was slightly higher than the number of tags recovered from the sea fishery. The majority of these were collected from the nearby Opløy Fjord.

### Economic analysis (cost/benefit)

It was difficult to collect data for use in a cost/benefit analysis, partly because scientific aspects were assigned greater importance in the projects. In order to test specific hypotheses it would be necessary to keep groups of fish separate during production and release, to tag a proportion of the fish, and to monitor the catch more carefully. These operations would increase costs and reduce benefits. However, based on the experience of project WC3 – Opløy, it was possible to reach some general conclusions.

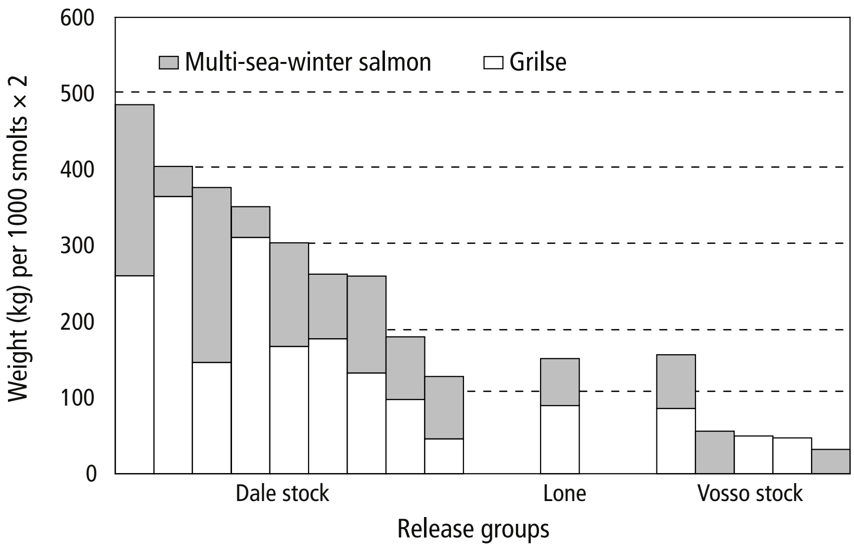
It is not possible to financially balance the operation of a sea-ranching plant through income from the sale of returned salmon. Approximately one percent of the fish returned to the release site. Calculations showed that this must rise to 13 percent before income matches costs. The economy of a sea-ranching project is improved if at least a part of the income is based on the sale of sports-fishing licences. In WC3 – Opløy income per kg fish was clearly higher for salmon that were caught by anglers than salmon caught by the project staff. A further development of this idea, not tested during the programme, would be to include fishermen who catch salmon in the sea, e.g. if the fishermen in the region pay a fee to finance the releases.

The total economy of sea ranching is obviously better than the economy of a local enterprise that raises and releases salmon on its own account, because a high proportion of the fish are caught by fishermen that do not pay their share of the costs of the releases. For these fishermen the ranched salmon supplement their catches of wild (and escaped farmed) salmon. The best-performing single release group comes close to being in balance when the economic consequences for the sea fishery are included, but the total economy of the Opløy project still are poor, dependent on which “best-case” assumptions that are made.

One reason for the poor economic results was the rapid development of the aquaculture industry in Norway during the past two decades, which has resulted in roughly a 50 percent reduction of the market price of salmon in 10 years. In addition, catches of wild salmon, i.e. survival of salmon in the sea, has been at a historically low level during the 1990s. In the present situation in Norway, it is likely that if the benefits could balance or exceed the costs of sea ranching, then the fishing licence model should be evaluated, and the release site/river ought to be chosen so that conditions are “optimal” for this approach (length of river, accommodation, distance to airports, cities, etc.)

The benefit may also be measured in terms of the quantity of food produced. Estimates of the total yield in kilograms of adults per 1 000 smolt released in WC1 show that the outcome varies substantially between stocks and family groups, roughly between 50–500 kg per 1 000 smolt released (Figure 18). When the fact that the mean smolt weight was approximately 50 g is taken into account, the total catch of the poorest surviving group is roughly equivalent to the weight of the smolts released. For the best group the weight is increased 10 times from release to recapture, demonstrating a genetic potential for optimisation. However, based on the present

FIGURE 18. Estimated total weight (kg) of returning adults per 1 000 released smolts in WC1 in 1993. Numbers are multiplied by two to account for tag loss, tag mortality and non-reported tags (see Methods of tagging for explanation). The results for grilse and multi-sea-winter salmon are shown separately for the three stocks and two of them are further subdivided into family groups

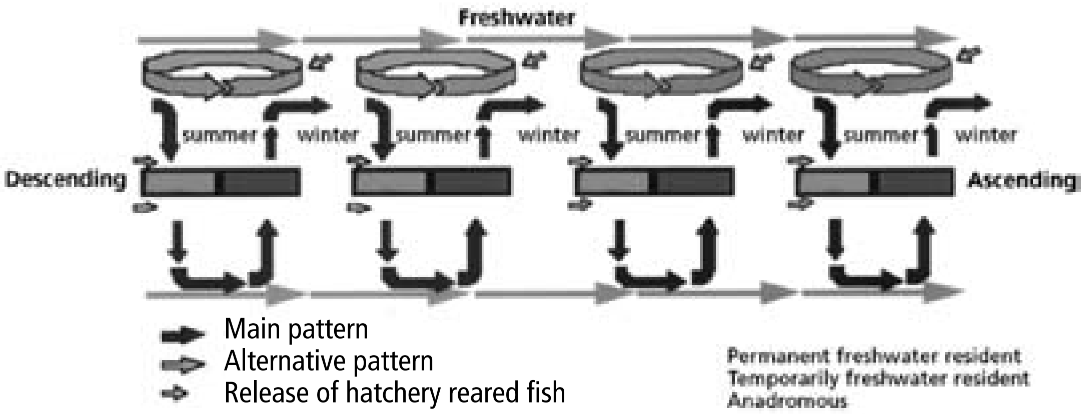



production cost of cultured smolts of US$1, and a price per kg of cultured salmon of US$3 and of wild salmon of roughly US$5, then the total catch would have to exceed 200 or 330 kg per 1 000 smolt to balance the budget, before the extra costs of release and recapture are included. If 50 percent or less of the adults are caught at the release site, then the income will be too low. This exemplifies the conclusions above. The benefits would have to be increased substantially by organizing a recreational fishery if sea ranching is to be profitable.

### Associated management strategies

Due to the low natural survival rates of wild salmon since the late 1980s and the existence of high numbers of escaped farmed salmon, many native Norwegian stocks are endangered. Genetic screening of a few of more than 500 salmon stocks in Norway has shown significant genetic differences. Wild salmon stocks represent genetic resources that may be lost if not protected. The precautionary approach implies that large-scale releases of hatchery-reared smolts should be carried out with caution. High rates of straying of released smolts are of most concern. On the basis of experience gained during the PUSH programme it is clear that straying rates and geographical patterns of straying are difficult to forecast. Before sea ranching is allowed from a specific location we recommend that these factors should be specifically studied, for example using externally tagged smolts, as long-distance as well as local straying may result. This information should be included in the description of the release site, and it may be preferable to tag a number of smolts every year as the pattern of straying may change when handling procedures and release methods do so.

FIGURE 19. Migratory patterns in anadromous, permanently freshwater resident and temporarily freshwater resident Arctic char




# **Arctic char** *(Salvelinus alpinus)*

As its name implies, the Arctic char is an Arctic fish species with a circumpolar distribution in the northern hemisphere. Char display two main different life history patterns, freshwater resident and anadromous. A combination of these two main ecological forms may be displayed in locations with upstream access from the sea; characterised as temporarily anadromous or temporarily freshwater resident (Figure 19). Freshwater resident char are the most common form. In southern (south of 65° N in Norway) and landlocked locations (mainly lakes), char are freshwater resident and complete their entire life cycle in freshwater. Generally, freshwater resident char are about 20 cm total length, and they are often found in overcrowded and stunted populations. Anadromous char are common in northern Norway, and are especially frequent in systems where there are lakes with good upstream migrating conditions for fish from the sea. Char smoltify, but external signs of smoltification are less obvious than for other salmonids, and char is the least anadromous of the anadromous salmonid fish species. Most fish home back to their native river when they reach maturity. In Norway, the main period for sea residence is June to July. Most char remain close to their native river (<30 km) during their sea residence.

No reliable catch statistics for Arctic char are available. The first attempt to sea-ranch char was made in Halsvassdraget, North Norway in the late 1980s (Finstad and Heggberget, 1993). The smolts were produced in a salmon hatchery with the same technology as for salmon smolt rearing. The initial releases of char smolts yielded high recapture rates, 10–30 percent after one stay (two months) at sea. This recapture rate was much higher than has been observed for most other salmonids. However, because of the low rate of growth of reared smolts in the sea the increase in biomass from smolt to mature fish was low, and in most cases negative. Char need 2–5 stays at sea before they reach maturation. Therefore, figures for total survival and biomass increase after the number of sea stays necessary to produce mature fish (0.5–2 kg) was the ultimate goal of the char-ranching programme. The possibilities were related to high survival rates of char during sea residence, while the limitations and problems were linked to the low growth rates of hatchery-reared fish. At the beginning of the programme little information existed regarding the life history of char, compared for example, to what is available for Atlantic salmon, and likewise as regards cultivation or sea ranching. The main goals were to investigate the possibilities for sea-ranching char and to provide basic biological knowledge that could be of importance in the future development of sea ranching and wild stock enhancement.

## METHODOLOGY OF THE SEA-RANCHING PROJECT

### Broodstock selection

Before the programme was established it was decided that broodstock of local origin, and for the experiments in the Halsvassdraget and the Mokkelandsvassdraget (see Figure 20), native char were used as broodstock fish. In the Halsvassdraget, the majority of broodstock constituted of anadromous char, while the majority of broodstock in the Mokkelandsvassdraget constituted of freshwater resident char.

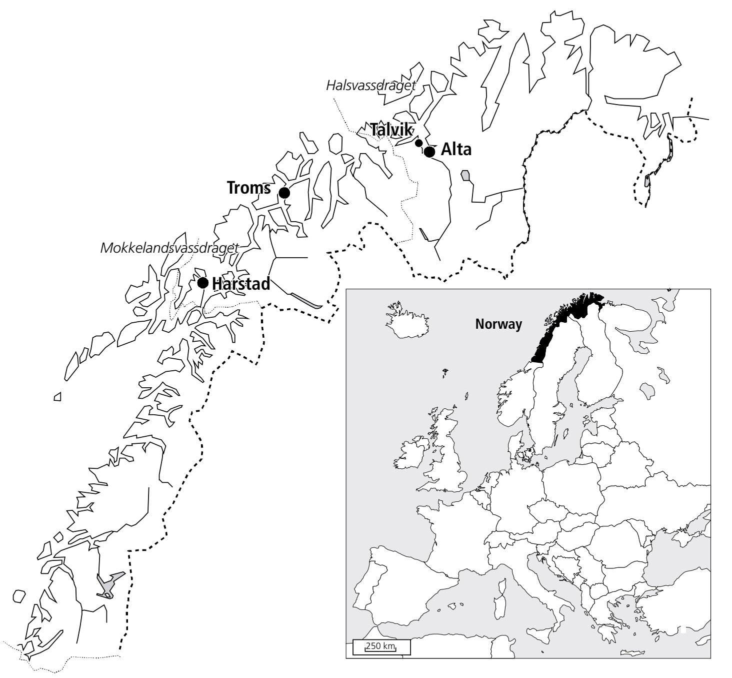
### Rearing and release strategy

Char is a cold-water adapted fish species, and can easily be artificially reared by employing the same technology as for Atlantic salmon smolt production. Compared to salmon, char grow at lower water temperatures and can thus be produced with less energy demand for water heating during the winter. Char can also be kept at higher densities in the hatchery. Both one- and two-year old smolts were produced. Experiments were also carried out with releases of presmolt char and with wild freshwater resident char that had been fed for a period in the hatchery before release. The experimental fish were released in two streams, Halsvassdraget in Finnmark County, which was the main experimental stream and in Mokkelandsvassdraget in Troms County (Figure 20; Anon., 1998b). A smolt hatchery was located close to the fish trap in the River Halselva. The smolts released in the Mokkelandsvassdraget had to be transported from a hatchery in Tromsø. For the sake of comparison, both wild char caught during migration in the fish traps and hatchery-reared char were tagged.

### Management of the recapture phase

As described above two main projects, including the production of release material and detailed analysis of recaptures were carried out in 1990–94 in the Halsvassdraget in Finnmark and

FIGURE 20. The main distribution area of anadromous Arctic char in Norway (shown in black on the inset map). The two main experimental sites were close to Talvik (Halsvassdraget) and Harstad (Mokkelandsvassdraget)



the Mokkelandsvassdraget in Troms (Anon., 1998b). Traps were set in the streams to catch both ascending and descending fish, and the traps were sited close to the estuary of the rivers. In parts of the experiments, sub-samples of release groups of smolts were released upstream of the fish traps to analyse the migratory behaviour. Presmolt char of 8– 14 cm body length were released about five to six months before smolt migration in a lake upstream of the fish trap in the Halselva. The proportion emigrating as smolts in the following spring were recorded in the fish trap.

To monitor recapture rates, individual growth and migration patterns, sufficient numbers of experimental fish were individually tagged with visible external tags. Carlin tag is the most commonly used tag for salmonids in Norway, which is easily detectable with an individual number. A reward is given to fishermen reporting tagged fish, which helps to ensure that fish captured outside the release area are also reported. In cases where information about recaptures outside the site of release is not required, simpler and less expensive tagging methods than Carlin tagging were employed. Colour tagging or finclipping were used to compare survival and growth of different groups of fish that were released. These tagging methods enabled us to compare the performance of smolts of different ages and sizes.

### Genetic monitoring

No genetic monitoring was carried out.

### Fish health management

The fish were reared according to the fish health regulations for Atlantic salmon in Norway. To avoid transferring disease between wild and cultured fish, the groups were kept separately in both the hatchery and fish traps. The ranching experiments were carried out during a period (1990–1994) of extremely high rates of infection of salmon lice along the Norwegian coast. This situation is now improving, mainly due to synchronised delousing in Norwegian salmon farms, but also due to extremely mild winters in the early 1990s on most of the Norwegian coast. Apart from high intensity and high prevalence of salmon lice on returning char, no other diseases were reported. The main effects of salmon lice are reduced survival and reduced growth rates during periods in the sea.

## EVALUATION PROGRAMME

### Sea-ranching goals

The char programme had the following main objectives:

- To establish basic knowledge relevant to the future development of sea ranching and mitigation of anadromous char stocks.
- To compare the performance (survival, growth) of different ecological groups (anadromous vs. freshwater resident) and wild vs. hatchery reared char in sea ranching.
- To analyse the possibilities with char in sea ranching and mitigation of wild stock.

### Measures of success

One of the main objectives of the experiments was to compare the performance of wild and hatchery-reared char (presmolt, one- and two-year-old smolts). Studies of some basic life history patterns in anadromous char in the Halsvassdraget (Finstad and Heggberget, 1995) showed that the smolts of wild char (first-time migrants) in the Halsvassdraget varied between 13 and 27 cm body length, and individuals between 17 and 20 cm had the highest survival rates during their first stay at sea. The main period of smolt descent is between 1 June and 22 June, while most of the wild char ascended River Halselva after their first stay in the sea between 29 June and 3 August (Anon., 1998b). Overwintering adults emigrated 15 to 30 days earlier than smolts (first-time migrants), and the largest individuals descended early in May. Hatchery-reared char released as presmolts in a lake upstream of the trap, ascended later and over a longer time span than wild smolts. In both groups the largest individuals ascended earliest, while smaller and often immature individuals ascended later in the season. If the data from the recaptures of hatchery-reared char is compared to the data from the monitoring of wild char, wild char display significantly higher survival (Figure 21). The most striking differences in survival after each sea stay are seen between wild and hatchery-reared first-time migrants (smolts). Hatchery-reared smolts had survival rates of about 10 percent, while wild char (>25 cm) had survival rates of about 68 percent. In both wild and hatchery-reared char survival increased with the number of periods in the sea. This is mainly an effect of increasing size with increasing numbers of sea stays, but is also an effect of experience in older fish (Heggberget, unpublished). The highest return rates were obtained for wild char during their third stay in the sea (92 percent), which is extremely high compared to other salmonid fish species.

Wild char stayed at sea for a significantly shorter time ($p<0.001$) than hatchery-reared char, with means of 32 and 57 days respectively (Finstad and Heggberget 1995). In spite of the shorter time spent at sea, wild char displayed a significantly better rate of growth than hatchery-reared char. This is shown in Figure 22, where both survival and growth are included in calculations of biomass returned in relation to biomass descended. The results of calculations of returned biomass in relation to biomass of fish descended, (released in hatchery reared fish), are essential for calculating the economics of traditional sea ranching, since the financial return is based on fish meat sold. The results of the Halsvassdraget study clearly show that the increase in biomass is far below what is needed for traditional sea ranching with char to become financially viable.

It should be emphasised that some of the results obtained in the char programme are dependent on the methods employed and on the current situation in the sea as this affects the survival of anadromous salmonids. The results of releases of

FIGURE 21. Recapture (%) of wild and hatchery-reared Arctic char after 1–4 sea stays

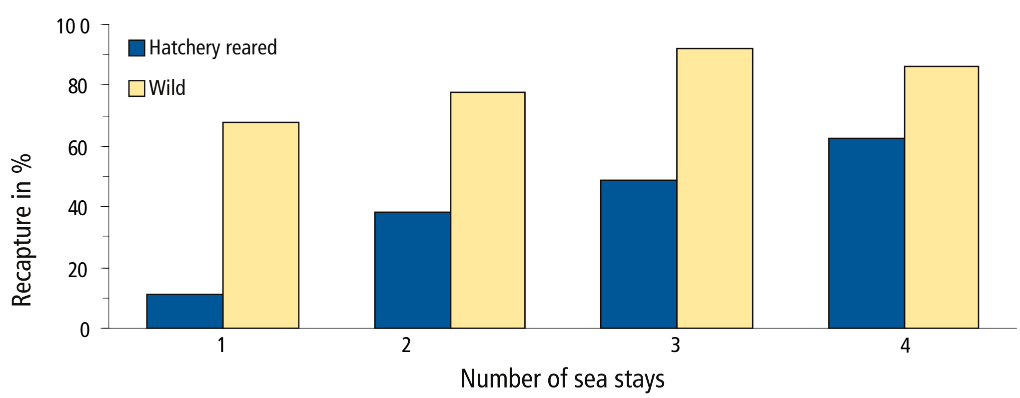
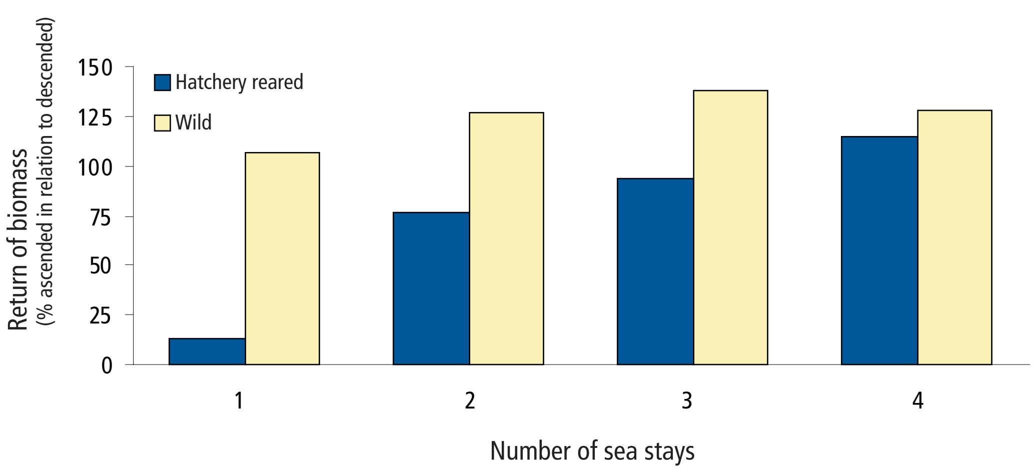
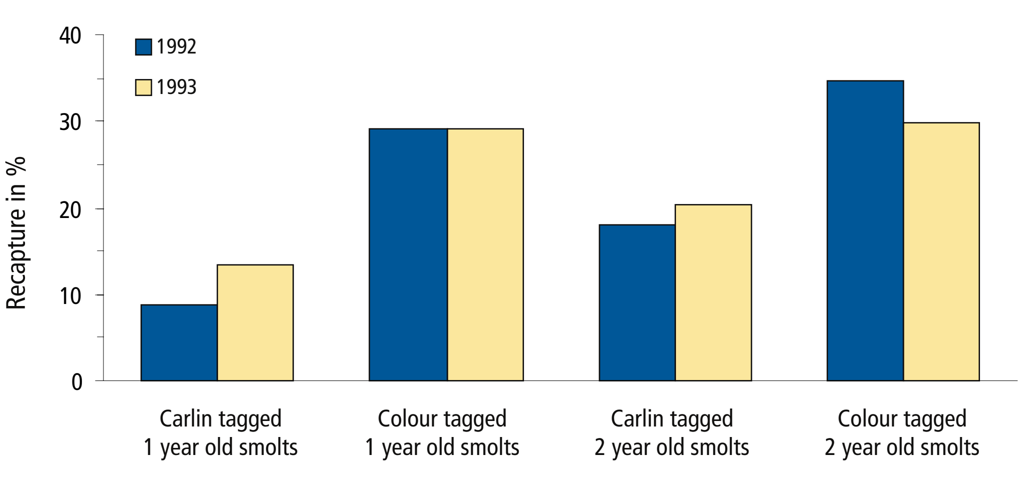


FIGURE 22. Return of biomass in wild and hatchery-reared Arctic char




hatchery-reared char smolts in 1992 and 1993 are examples of factors that affect the results of experiments with char. Tagging is necessary in experimental work because detailed information about release groups is essential. Depending on the goals of the experiments, different tagging methods were employed. The results clearly indicate that survival is affected by the method of tagging; external tags produce higher mortality than internal tags (Figure 23). It can also be seen that two-year-old smolts perform better than one-year-old smolts. This is because two-year-old smolts are larger, but is also an indication that factors connected to production procedures in the hatchery are important to the success of released fish. In a commercial operation, it is normally not necessary to tag the fish by external tags. It has frequently been shown that all extra handling of fish, such as tagging, reduces survival. Some tags will also be lost or ignored at recapture. The results presented for char based on the experimental work described here, therefore, represent absolute minimum rates of recapture. In a practical commercial operation, both survival and growth increase would be higher as a result of less handling and manipulation of the fish. It should also be mentioned that the experiments with char were carried out in a period with high infections of sea lice on char, which negatively affects both survival and growth during residence in the sea.

FIGURE 23. Recapture rate of Carlin- and colour-injected tagged 1- and 2-year old hatchery-reared smolts in 1992 and 1993 (Anon., 1998b)



### Contribution of hatchery fish to fishery

During the experimental period of sea ranching char, about 100 000 smolts were released in the river Halselva alone. This contributed significantly to the fisheries, both in the sea and in freshwater. On the basis of external of tagging of some of the released fish, detailed reports on recaptures are available, showing that most recaptures were within 30 km of the site of release. The results clearly show that smolt releases are a possible means of enhancing natural stocks of anadromous char. The results also show that there is a potential for improving the performance of hatchery-reared char relative to wild char.

### Economic analysis

In the economic evaluation different approaches were evaluated, as e.g. production combined with angling or "trophy" fishing (Anon., 1998b). There is a potential, but so far such activities have not yet commenced. Concerning aquaculture production of char, PUSH has performed the necessary evaluations to stimulate such activities, either as fish farming or in combinations with sea ranching. The last few annual productions of char reached 300 to 400 tonnes. An increase in the exportation rate of this species is unlikely since char is less known in middle and southern Europe. The marketing will be costly if char is to reach for instance the level of rainbow trout with 20 000 tonnes annually. Due to limited funds in push the activities had to be finalized in 1993/1994.

## GENERAL CONCLUSIONS AND FUTURE PROSPECTS

Ever since humans began to harvest marine fish stocks there have been wide fluctuations in yield with respect to quantity, size and species composition. There may be several causes for this, and the blame has often been put on individual elements such as overfishing or environmental factors. During the past hundred years we have tried to enhance and rebuild fish stocks. In most cases, the goal has been to strengthen the fisheries of a specific species or stock, while we are currently experiencing a greater need to rebuild stocks threatened with extinction. As shown in this paper, stock enhancement is not straightforward, and comprises much more than merely releasing fish or crustaceans.

### Main conclusions

Knowledge acquired through the PUSH research programme has provided valuable insight into factors that regulate fish production in our fjord and coastal areas. It is concluded that the economic aims for sea-ranching activities must be evaluated in a long-term perspective, and beyond the duration of the PUSH programme. It was not possible to develop commercial sea-ranching activities for any of the species concerned. However, biological and ecological requirements have been clarified.

Sea ranching of cod, salmon and char has been terminated, while promising results with lobster have led to a continuation for a few more years in order to cover more of the recapture period. We describe below in more detail the requirements for stock-enhancement or sea-ranching activities that we have reached for the four species presented in this paper.

### Biological and ecological requirements

In EUROPEAN LOBSTER knowledge acquired from the large-scale hatchery run by Tiedemans at the beginning of the 1980s formed the basis of the stock-enhancement programme. For technical reasons, the environmental conditions in the hatchery were not as stable as could have been desired. Survival from hatching to settlement varied from year to year from 3.1 to 4.6. The tagging technique employed proved to be reliable, and juveniles as small as 8 to 10 mm carapace length could be tagged. From 1990 to 1994 about 170 000 juveniles were produced and about 128 000 of these were released at Kvitsøy in southwestern Norway. Some releases were also made in other areas, but due to financial constraints they could not be followed up. It is concluded that it is possible to increase the total population in an area by releasing cultured juveniles. It was also shown that cultured lobsters do not replace wild lobster, but represent an addition to the stock. An important task in relation to the release experiments has been to increase our knowledge of basic population dynamics parameters such as mortality, growth, recruitment and maturation. In this respect is has been shown that with a minimum legal size of 25 cm total length (introduced on 1st October 1992) all females have spawned once before capture and a majority also twice. No cultured lobsters have been found outside the release area, and preliminary results also show very little local migration. The majority were stationary, but few specimens have travelled distances of 2–3 km. Furthermore, genetic studies have demonstrated that genetic changes are also likely to occur when lobsters are cultured, ant it is therefore important to carefully evaluate number of lobster used as broodstock (genetic drift) and differences between wild and farmed environments (selection).

For **Atlantic cod**, one of the prerequisites of the release experiments was to develop several production units in different coastal and fjord areas. Cod juveniles were produced either in seawater enclosures, plastic bags, large containers or small indoor tanks. There were varying results in all the systems, but a total of 1.2 million cod juveniles was produced, where of 720 000 were tagged and released in various coastal and fjord locations, providing important information on migration, survival, growth and recapture. Various release strategies were tested, including training juveniles to develop normal anti-predator behaviour. Recapture rates ranged from 0 to 30 percent depending on area, time and size at release. In most of the release areas, a positive correlation between the size at release and survival was observed. Individual growth was highest in the outer coastal areas. The results also showed a slower rate of growth in northern fjord areas than in corresponding southern areas. Ecosystem analyses were performed for the most important release areas in Hordaland and Troms, and large differences were found in carrying capacity, and growth and survival rates.

The unique knowledge obtained, will be important both for the further development of stock enhancement in Norway and also as a basis for evaluation of stock with marine species in other countries.

In **Atlantic salmon** the production of smolts is well understood from intensive aquaculture, and was found suitable for sea-ranching purposes as well. In the release experiments emphasis was placed on studying variation between large and small watercourses, releases directly in the ocean, time at release, release methods and comparisons of the performance of different stocks. A great deal of background information relevant to the evaluation of smolt quality and suitable release methods has thus been obtained. A total of 1.2 million smolts were released. No systematic differences in recapture rate or straying could be found between releases made in watercourses close to the coast and those further out in the fjord system, but the geographical straying pattern varied between the specific release sites. In general, mean yearly recaptures were low, ranging from 0.5 to 3.8 percent. However, there was a high degree of variation between release groups; from close to 0 to 12.8 percent total tag recovery. These differences, which seemed to be related to the treatment and origin of the released fish, probably indicates a potential for further optimisation of the methods of salmon sea ranching. The fishing effort for salmon increased in areas with returning ranched salmon, and the proportion of wild salmon in the catches increased with distance from the release site. Cultured salmon should therefore, in principle, be harvested at or close to the location of the release. Egg batches were kept in quarantine until the brood fish had been screened for diseases, and no diseases were detected prior to releases. The negative interaction between wild and sea ranched salmon of most concern was the high straying following many of the releases. Cost/benefit analysis gave negative results, partly because of too low returns and because 50 percent or more of the adult salmon was caught outside the release area. The highest income was seen when the fishery at the release site was organized as a sport fishery. There may be a need to include the sea fishery in a region in a sea ranching model in which the costs of the releases are shared. One alternative, also investigated, was to release yolk sac fry in the upper tributaries of a river. This method resulted in a non-expensive smolt production of at least one individual/100 $m^2$ .

Research on **Arctic char** provided valuable information regarding the production of smolt relative to intensive cultivation. The projects focused on factors that influence the quality of the cultured smolts, and suggested that a combination of light, temperature and feed concentration was of importance. The use of wild char smolt as an alternative to commercially produced smolt was studied, but even though releasing wild char reduced the costs per smolt, factors such as variations in age, maturity and parasite attacks became a problem. Char spend much shorter periods, approximately 30 to 50 days at a time, in the ocean than salmon. Char is a northern circumpolar species with several ecological forms, and the seaward migration pattern is probably an adaptation to extreme climatic conditions with large seasonal changes. It is therefore reasonable to assume that feeding migrations take place because food is more readily available in the oceans than in lakes or river systems. About 123 000 individuals were released. In comparison with other salmonid species the recapture percentages were high, but somewhat variable. While only 10 to 30 percent of the first-time seaward migrants survived the ocean period, the return varied from 70 to 90 percent for larger fish (veterans). The proportion of char that made a seaward migration (the anadromous part) varied from river to river. It is uncertain whether there is a genetic difference between stationary and anadromous char in the river systems. The bottleneck in sea-ranching char is the high mortality suffered by first-time seaward migrants. Fish below 20 cm total length suffered a mortality of over 90 percent during the ocean phase. Char spend most of the ocean period close to the shore in areas with such fish species as cod, and a high degree of predation can thus be expected.

Sufficient knowledge is now available to cultivate char where wild stocks have been reduced or destroyed. It has also been shown that hatchery-reared char can contribute significantly to the fisheries, both at sea and in freshwater. The potential for char ranching is related to the combination a commercial fishery with the development of a sports fishery for returning fish. The quality of hatchery-reared char can be improved by further experiments on rearing technology. Hatchery char smolt production is only about 10 years old, while hatchery salmon smolt production has been going on for about 50 years. Thus, increased experience of smolt production and improvements in release techniques will certainly improve the results of char ranching.

### Juridical requirements

Stock enhancement and sea ranching are fields or disciplines that requires different legal approaches and efforts. In a depleted stock, the fishing pressure is already heavy and will most likely increase further as a result of the releases itself. This has, among others, been observed in the enhancement project with lobster. In this respect, the increase in the total stock will be of a short-term character. A sustainable strategy aiming to restore a stock to previous recruitment levels must include new approaches in management. Ideally fishing activities should cease for a period of time, but such actions are usually very difficult, not say impossible, to introduce.

On the other hand, before a commercial sea-ranching industry can be established, legislation that ensures the right to recapture the released animals will have to be developed and introduced. A proposal for a new law for sea ranching was prepared during the programme, as Norway had no legislation concerning sea ranching. This means that neither private nor public institutions can claim ownership of released organisms, though there may be exceptions when these are marked or tagged. The development of a sea-ranching industry requires thorough examination of the legislation, and it was necessary to draw up an Act on sea ranching. A special legislation group was appointed to carry out this task and its recommendations were made in 1994 (Anon., 1994). The committee suggested a law of exclusive rights for releases based on applications and concessions assigned by relevant public authorities. Unlike "general rights" ("commons": the legal right of access to private land) to fish, assigned rights would secure exclusiveness. The report was later sent out for public reactions. The Ministry of Fisheries evaluated the recommendation in 1996. In autumn 1999 the final law proposal was sent out for reactions and evaluations, and was submitted to Parliament in the spring 2 000 session. The new *Act on Sea Ranching* will only deal with molluscs, crustaceans and echinoderms. Fish are not covered, mainly in order to reduce possible conflicts of interest. The new Act will ensure an exclusive harvesting right for the owner of the permission to release.

### Economical requirements

Economic evaluations of the release projects were considered important, and profitability analyses were made, both with respect to the possible development of private enterprises as well as to the evaluation of socio-economic aspects. In general, survival rates in the sea were too low to make sea-ranching activity profitable, and the market price for cod, salmon and char would have to double or triple to make commercialisation worthwhile. However, reducing costs per animal released as well as including steps to improve survival and growth are possible approaches that can improve the prospects of profitability. Not even with lobster does appear that there are any private enterprise developments in the short run, although enhancement seems to have the potential to become socio-economically viable. In this respect, offspring or second-generation organisms must be taken into consideration and it is assumed that the effective or total production will increase as a result of the releases.

### Strengths

The strength of the programme was that the entire range of Norwegian expertise was involved. Adequate budgets were provided to enable the projects to obtain the knowledge needed to answer the question of whether ranching of the species concerned could become financially viable. This created a platform for future collaboration between scientists from different organizations and institutions in

Norway. Collaboration between disciplines such as biology, economics, social sciences and technology were developed through the PUSH programme and were shown to be important in later research activities, both in Norway and elsewhere.

### Weaknesses

One may ask whether the objective of PUSH, "profitable industry", was capable of being achieved before biological and economic requirements were known. The board of the PUSH programme emphasised that patience had to be shown regarding goals related to employment and industry. As early as 1992–93 it was pointed out that the financial goals for sea ranching would have to be evaluated in a long-term perspective, and beyond the duration of the PUSH programme. This conclusion has not changed.

The programme period was too short to repeat important experiments because the life cycles of some of the species involved are of the same length as the duration of the programme. The releases of salmon and char were carried out during a period with low "natural" survival caused by a negative marine productivity cycle and high infection rates of sea lice. To some extent the management of the programme was too politically driven, and it became more important to release large numbers of organisms than to carry out experiments according to scientifically accepted methods. It would probably have increased the chances of success if fewer fish had been released, the number of release sites increased and the monitoring period extended. This would have improved the chances of identifying suitable release locations for sea ranching in Norway. A better way of reaching the goals of the programme would therefore have been to carry out more scientific experiments designed from the general lack of knowledge relevant to sea ranching, than to release high numbers of organisms in a few locations from the point of "profitability".

### Evaluation of other fishery management options

It is an interesting question whether regulating the ordinary fishery more strictly for a period can be a more cost-effective strategy for increasing stocks than accepting the costs of producing juveniles for release purposes. Such analyses did not form a part of the programme when it started, nor were such analyses given much attention in the course of the programme. One reason for this is that it is not easy to evaluate the effects of different fishery management options. Some concern was expressed about Atlantic cod and lobster stock management at the symposium arranged by PUSH in September 1997 (increase in minimum size).

The Board of Push produced a synopsis of stock-enhancement projects in other countries on the basis of several study trips. In the western United States salmon resources are controlled by means of various techniques, and declining yields are believed to result in part from shortcomings in the regulatory process. Spawning refuges, habitat protection and restoration, and the construction of fish reefs are such examples.

### Prospects and lessons for future programme

Several lessons can be drawn from the PUSH programme, but among the most important is that to manipulate marine ecosystems is extremely difficult owing to the many feedback mechanisms, such as density-dependent growth, mortality, etc. Furthermore, all background information must be thoroughly evaluated before commencing a stocking programme. One should not maintain unrealistic expectations regarding the development of commercial activities in a short time frame, as also strongly emphasized by Hilborn (1998). The development of commercial activity requires there is a solid biological and ecological basis for increased yield. This can only be ascertained if we know the scientific basis, in which case the commercial prospects can be evaluated and assessed via ordinary economic models.

Optimal collaboration between associated disciplines such as ecology, economics, technology, social sciences and the fishing industry will be required in the development of alternative sea-ranching activities in the future. It is also essential to recognize that developing economically and ecologically sustainable techniques of sea ranching with different species will take some time from the first attempts to practical operation. Patience will therefore be necessary in future work if we are to develop a new industry based on sea ranching.

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