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Rearing of cod in Masfjorden 1982-1992

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CONTENTS

1. ENGLISH SUMMARY

Masfjorden near Bergen, western Norway, was chosen as a site for an interdisiplinary research program on sea ranching of cod. The aims of the program were; to investigate the possibilities of enhancing the cod stock in the fjord by release of artificially reared juveniles; elucidate the physical and biological factors which determine the carrying capacity for cod in a fjord; describe biological effects after the releases. An important strategy has therefor been to study the fish populations and other parts of the ecosystem before and after the manipulation. In Masfjorden the most important codfishes are saithe, poor cod, pollach and cod, of which cod comprises 5-15 % in numbers and 45-50 % in biomass. During 1986-89 the number of wild cod in the fjord was about 38 000 - 112 000 individuals (0-group not included). In biomasse this equals 27-30 tonne. The strength of the year-classes 1984-1989 varied with a factor of 10 as 1 group. The cod feed in shallow waters in competition with the other cod fishes. Both results from the field and model simulations indicate that the carrying capacity for cod in Masfjorden is 30-40 tonnes. There is a positive correlation between the abundance of zooplankton, food organisms of the cod, growth and recruitment of cod. Model simulations indicate that production of cod depends on the velocity of exchange of water between Masfjorden and Fensfjorden, as this watertransport brings zooplankton from the coastal water. The carrying capacity seems to be positive correlated with the abundance of zooplankton. Twenty-one releases of juvenile cod have been performed during 1985-91, of which four have been large-scale, 27 000 - 180 000 individuals. To evaluate the effects of the releases we have monitored the survival, growth, liver index, condition factor in the release area and in an control area, for cod and the other cod-fishes. The stomach content of the cod and development of selected prey populations were also followed. Mass releases of 82 500, 61 000 and 28 000 individuals were performed in 1988, 1989 and 1990, respectively. The releases led to significant higher numbers in the release area than in the control area when the cod was at the early 1-group stage. When the cod reached the 2-group stage no difference in abundance between the two areas were found. We suppose that density dependent mechanisms resulted in higher mortality rates in the release area, and that shortage of food was the main factor. Thus, the three releases did not increase the production of cod in the fjord. Only minor effects were registered on wild cod and other fishes. Masfjorden was chosen for this program because it has an enclosed topography and a cod stock of a size that is possible to manipulate. From the results of the project we may conclude that a suitable habitat for cod enhancement in western Norway (better than Masfjorden) should be an open shallow-water system closely connected to the coastal water which is rich in zooplankton. One has to alternate between release areas, maybe each year, to avoid buildup of an older cod predator stock. Fishing effort should be changed from small cod < 2 years against older individuals > 3 years.

2. NORWEGIAN SUMMARY

Masfjorden i Hordaland ble i 1985 valgt som område for et bredt anlagt eksperiment med kulturbetinget fiske etter torsk. Formålet har vært; å undersøke om det er mulig å øke produksjonen av torsk i en fjord ved å sette ut pollprodusert torskeyngel; klarlegge de fysiske og biologiske forhold som er bestemmende for bæreevnen for torsk i en fjord; beskrive de biologiske effektene av utsettingene. En viktig strategi har derfor vært å undersøke fiskepopulasjonene og andre økologiske forhold både før og etter utsetting av torskeyngel.
I Masfjorden er de viktigste torskefiskene sei, sypike, lyr og torsk, hvorav torsk utgjør 5-15 % i antall og 45-50 % som vekt. Mellom 1986 og 1989 lå antall vill torsk i fjorden på ca. 38 000 - 112 000 (0-gruppe ikke medregnet). I biomasse utgjorde dette 27-30 tonn. Årsklassene 1984-1989 av vill torsk har som 1-gruppe variert med en faktor på 10. Torsken tar sin føde på grunt vann i fjorden i konkurranse med de andre torskefiskene. Både feltundersøkelsene og modellberegninger tyder på at bæreevnen for torsk i Masfjorden er 30-40 tonn. Det ser ut til å være en positiv sammenheng mellom mengden dyreplankton, torskeføde, vekst og rekruttering av vill torsk. Vi regner derfor med at bæreevnen varierer med mengden dyreplankton siden planktonet danner grunnlaget for produksjonen på de neste ledd i næringskjeden. Modellberegninger antyder at torskeproduksjonen er avhengig av vannutskiftingshastigheten mellom Masfjorden og Fensfjorden, siden denne vanntransporten bringer med seg dyreplankton fra kystvannet.
Det er foretatt 21 utsettinger i tiden 1985-1991, hvorav 4 var storutsettinger på 27 000 - 180 000 individer. For å vurdere effekten av utsettingene ble torskens og de andre torskefiskenes overlevelse, vekst, leverindeks og kondisjonsfaktor fulgt i utsettingsområdet og i et kontrollområde. Torskens fødevalg og populasjonsutviklingen til de viktigste byttedyrene ble også fulgt. I årene 1988, 1989 og 1990 ble henholdsvis 82 500, 61 000 og 28 000 torsk satt ut. På 1-gruppe stadiet førte utsettingene til at antall torsk var signifikant høyere i utsettingsområdet enn i kontrollområdet. Tetthetsavhengig dødelighet i utsettingsområdet førte til at ingen forskjell i antall kunne måles mellom områdene da torsken var på 2-gruppe stadiet. Disse tre utsettingene har altså ikke ført til øket torskeproduksjon. Tilgang på føde er trolig den viktigste tetthetsavhengige faktor for torskeproduksjonen i fjorden. Små effekter er registrert på vill torsk og andre arter som en følge av utsettingene.
Masfjorden ble valgt til dette eksperimentet fordi den er vel avgrenset og har en torskebestand på en størrelse som i utgangspunktet går an å manipulere. Av resultatene fra Masfjordprosjektet kan vi konkludere at et godt utsettingshabitat på Vestlandet (bedre enn Masfjorden) bør være et åpent system med god tilførsel av dyreplankton og ha mye gruntvannsarealer. Man bør veksle på lokalitetene slik at man ikke setter ut hvert år på samme sted. Fiskemønsteret bør bli anderledes enn nå, slik at fisk mindre enn ønsket størrelse ikke blir fisket.

3. INTRODUCTION

Is it possible to enhance local cod populations by releasing artificially reared juveniles?

This question was asked by G.O. Sars in 1864 and the theme has since been a controversy (DAHL 1906; SOLEMDAL *et al.* 1984). The lack of an appropriate marking method for released fish as well as high and variable mortality on the larval stage probably resulted in no measurable enhancement of coastal populations of cod. In 1983 the breakthrough for mass production of cod in a large pond was achieved (ØIESTAD *et al.* 1985). The advantage with this method is that large quantities of cod can be reared to desired size within an environment of few predators. This results in higher survival than what is found in nature.

Attempts to release pond-produced cod started in Austevoll in 1983 (summarized by SVÅSAND 1991). The early attempts were promising, and it was considered that releases could enhance local populations. Positive results from Austevoll gave the foundation for mass releases in Søndeledfjorden, Masfjorden and Balsfjorden.

"Cod in fjord. Masfjorden" started in 1985 as an interdisciplinary program which involved fisheries biologists, marine biologists, and nutrition biologists. The program also cooperated with geneticists. The objectives were to elucidate the physical and biological factors which determine the carrying capacity for cod in a fjord and describe biological effects after releases. The effect on the ecosystem was measured by monitoring of the population of cod and its most important competitors, predators and prey. It was considered important to start investigations of the fjord ecosystem prior to mass releases, and use this as an unmanipulated reference. This strategy in connection with releases of fish was recommended by e.g., ULLTANG (1984), GJØSÆTER (1986), and PETERMAN (1991).

Masfjorden was chosen for this program because it represents a relatively enclosed ecosystem of appropriate size, suitable for the amount of artificially reared cod available for release, and because it did have a local fishery. Masfjorden was also chosen because the Institute of Marine Research (IMR) previously had conducted hydrographical and biological investigations in the fjord, and because one could use the infrastructure of the IMR station Matre, located at the head of the fjord. Presumably there were more cod at other localities in the Hordaland county than in Masfjorden, and Masfjorden was possibly not the location with the greatest potential for enhanced production. However, Masfjorden was considered an appropriate location to test out two fundamental hypotheses concerning potentially successful sea ranching:

1. carrying capacity is not fully utilized because of sub optimal recruitment of wild cod, i.e., there are

underutilized resources which could support increased production.

2. By increasing recruitment artificially the cod will be given an advantage over its competitors which would cause it to occupy more of its resources (space, food) because of reduced competition.

Preliminary investigations started in 1985, and the first mass release was undertaken in 1988. We here report the results of research on fisheries and marine biology to 1992.

4. AREA DESCRIPTION

4.1 LOCATION

Masfjorden is situated north of Bergen (60° 50' N, 05° 25' E) (Fig. 1). The fjord is 25 km long, 0.3 to 1.5 km wide, with a maximum depth of 500 m and a sill at 75 m. The fjord is surrounded by up to 700 m tall mountains and the inner and middle part of the fjord have steep beaches. The outer part of the fjord and the area outside (control area) contain bays, islands and skerries, and therefore a higher proportion of shallow-water areas than the middle and inner parts of the fjord.

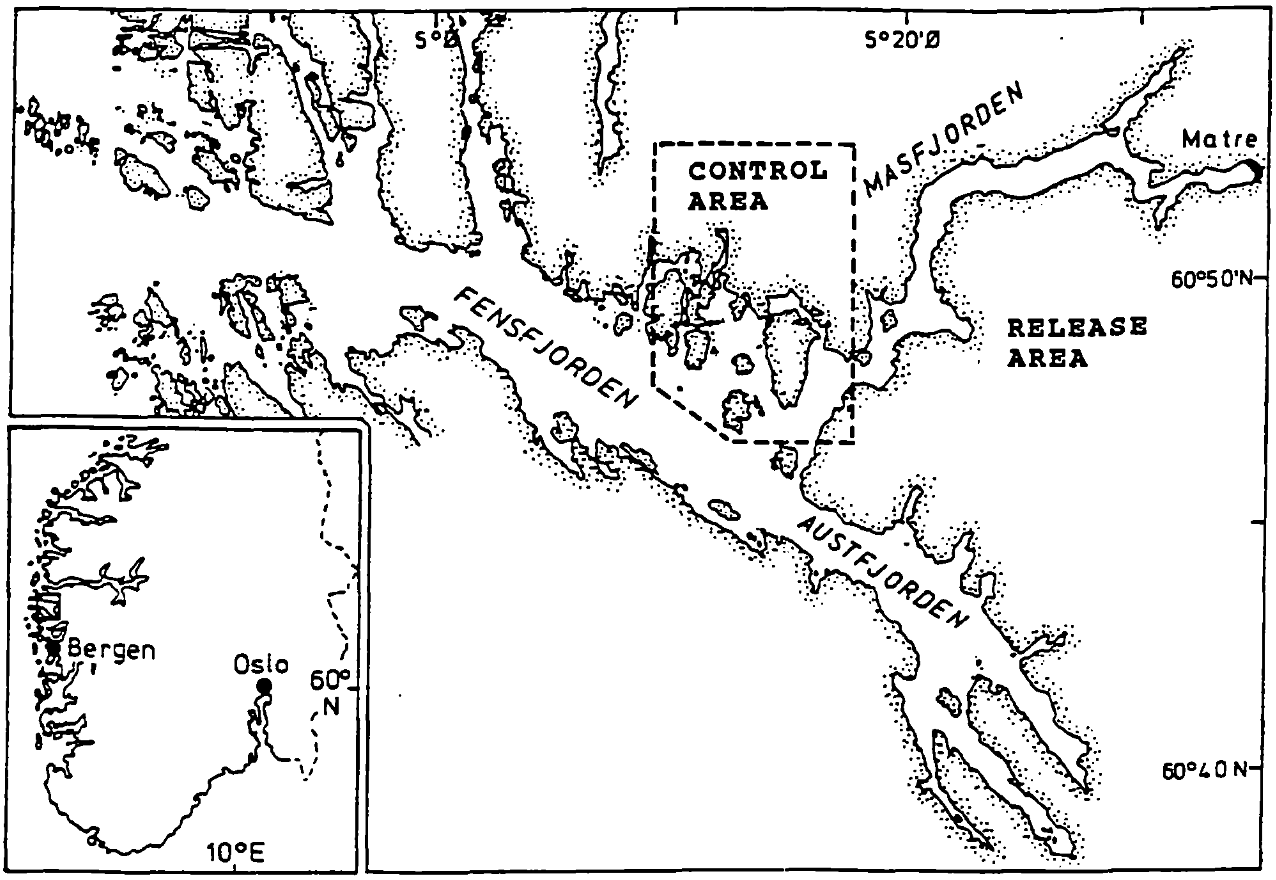


Fig. 1. Masfjorden and the surrounding areas. The release area covers Masfjorden from the sill to the head of the fjord at Matre. The control area extends from the sill to Fensfjorden (encircled by the stippled line)

4.2 HYDROGRAPHY

The water masses in Masfjorden can be divided into: brackish water (0-3 m), intermediate layer between the brackish water and the depth of the sill at 75 m, and deep water below the depth of the sill. The intermediate layer is divided into coastal water with salinity < 34.5 S, and North Sea water with salinity > 34.5 S. The conditions in the intermediate layer are dynamic and changes in the coastal current rapidly influence the Masfjorden though Fensfjorden. Downwelling on the coast caused by southerly winds create influxes of coastal water into the upper part of the intermediate layer in fjords of western Norway and outfluxes in the lower part. This situation is reversed during periods of northerly winds causing upwelling of deep water along the coast. During periods of down- or upwelling the local processes (wind, tides and freshwater run-off) become important for the hydrographic circulation patterns. The deep water in Masfjorden is usually not affected by processes in the intermediate layer, and several years may proceed between water exchanges in the fjord. The lowest oxygen content measured in the deep water during a period between two exchanges was 4 ml/l. Typical temperature and salinity in the deep water are 7-8 °c and 35 S. This information is based on AKSNES *et al.* (1989).

Temperature at two station in the fjord and in the control area are shown in Fig. 2. The temperature starts to rise in June and reaches a peak during summer in the outer part of the release area. In the inner part of the release area the maximum is lower at 1 m and delayed at 5 m as compared to the outer fjord area. During winter the temperature at 5 m depth is higher in the inner than in the outer fjord. The isolation effect because of the "artificial" freshwater release from the hydroelectric plant at Matre can explain this phenomenon, which has also been noted earlier in Masfjorden (AURE 1978). The salinity at 1 m depth in the outer reaches of the fjord is higher than in the inner parts of the release area, but below 5 m the salinity becomes practically uniform in the entire fjord (FOSSÅ *et al.* 1989). The salinity at the surface in the inner fjord varies considerably throughout the year probably being dependent of the freshwater release form the hydroelectric plant at Matre. Further out in the fjord salinity was highest during the winter, but annual variations are small.

4.3 VEGETATION

The vegetation of kelp and other macroalgae is very important for juvenile cod since it provides hiding places as protection against predators (KEATS *et al.* 1987), and these habitats also provide food. Kelp (predominately *Fucus serratus*, and *Laminaria* sp.) and sea urchins (*Echinus esculentus* and *E. acutus*) are mapped in Masfjorden by means of video camera and diving (FJELDSTAD 1991). The results showed that there was a larger area of dense zones of *Laminaria* sp. in the control area then in the release area. In the inner fjord the *Laminaria* forest disappears entirely. Sea urchins were registered as very abundant having greatest densities in areas with little kelp. A well developed kelp bed (*Fucus* species) is present in the entire fjord, also in the inner fjord by Matre, whereas the *Laminaria* zone is deeper in the outer fjord than in the inner fjord. Localities without kelp were found in proximity to mouths of rivers (FJELDSTAD 1991).

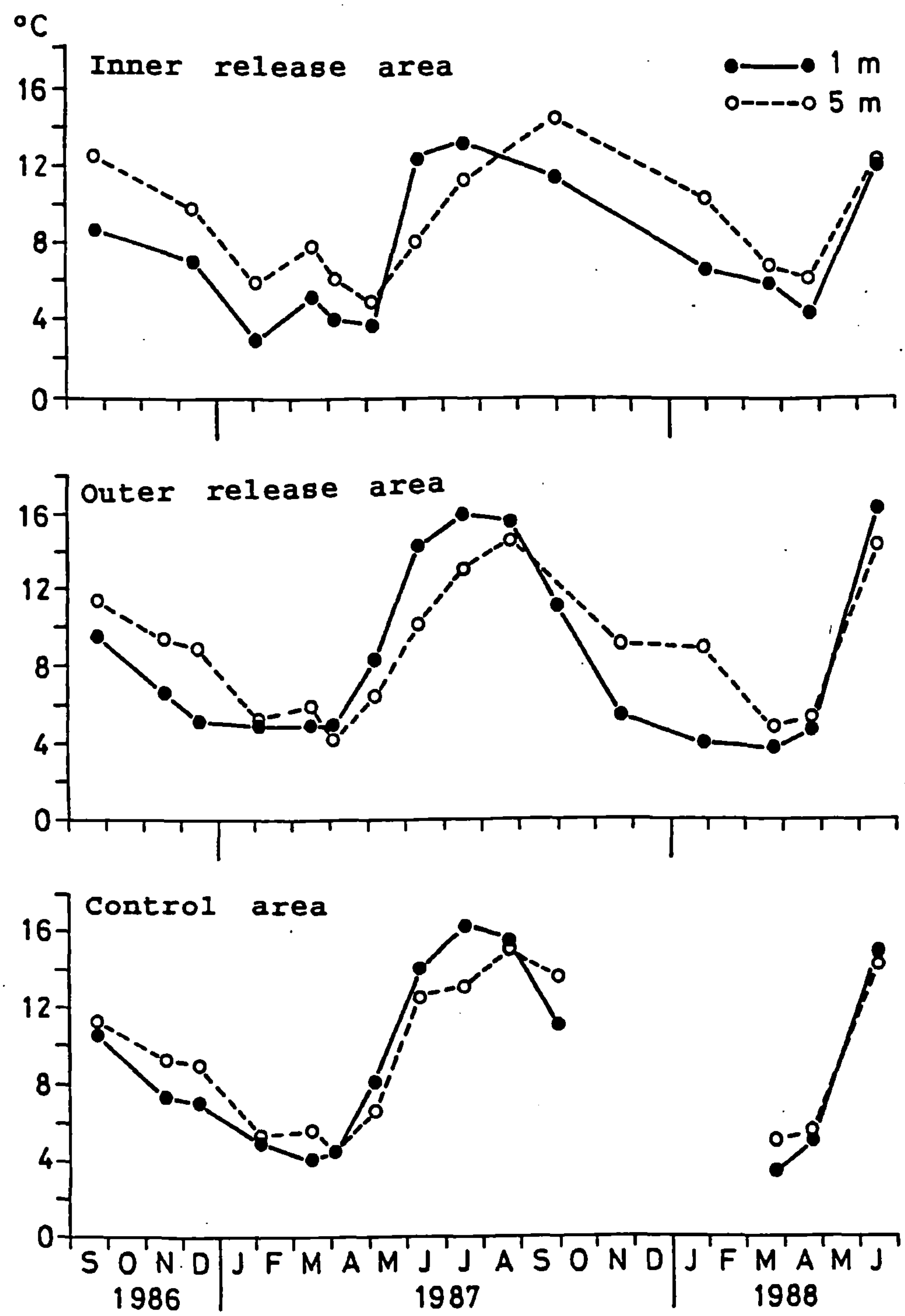


Fig. 2. Temperature at 1 and 5 m depth in the inner and outer part of the release area, and in the control area.

5. METHODS

5.1. SAMPLING

5.1.1. SAMPLING BY NETS

It has not been possible to use the same method to sample bottom fishes in Masfjorden as is usually used in more open seas. It was difficult to use trawls and acoustical methods to obtain biomass estimates because of the fjord topography; we therefore used nets to obtain fish. Three different nets were used: "trout nets" (size 32, 39 mm stretched mesh), "herring nets" (size 28, 45 mm stretched inner mesh) and "mackerel nets" (size 17, 70 mm stretched inner mesh). Herring- and mackerel nets are both trammel nets containing and outer net (261 mm stretched mesh). Fishing was done nearly each month since October 1985, mainly at depths 0-20 m, which include the main habitats for cod in Masfjorden. Groups of the three nets were set at random in the release and control areas (Fig. 1).

Selectivity curves for cod for each net type have been estimated (SALVANES 1991). By applying these curves, the catches of cod were corrected for net selection. This resulted in realistic length distributions which were considered representative for the population. An alternative way in which to obtain representative samples, is to combine (pool) different net types with known selectivity to get approximately non-selective net groups. It was shown that the net groups consisting of the three mentioned net types were approximately non-selective. We therefore used results from the net groups when estimating population parameters.

5.1.2. COMMERCIAL AND RECREATIONAL FISHERIES

Daily catch records have been kept by registered fishermen in Masfjorden. Information on numbers, length, weight, gear, time, location and depth were noted; the fishermen were paid for this. The local fish landing base have kept catches statistics for received landings. SALVANES (1986) provided an overview of species composition of catches for one of the years. Nets are predominately used during the fishery on spawning cod in January-March. During summer and autumn (July-December) cod and pollock are mainly caught as a bycatch during the eel fishery in traps at 0-6 m depth. The recreational fishery for cod in Masfjorden is considerable. The fishermen have also sent us information on tagged cod.

5.2 MARKING

At the start of the Masfjord project in 1985 there was no appropriate method for mass marking of cod in the order of 100,000 individuals. We therefore had to develop new methods.

Methods rendered useful are described below. We have to add that freeze -branding, which has been used successfully on salmon, in not applicable on cod. The mark disappeared within a couple of months.

Oxytetracycline (OTC) was used to mark cod before mass releases. OTC was given to the cod in their feed. OTC forms complexes with calcium and adheres to the bone structure as the fish grows. The mark will reflect a clear yellow light when, for instance, the backbone is illuminated by ultraviolet light. The method is described by NORDEIDE *et al.* (1992).

Genetically marked cod, reared by JØRSTAD et al. (1987) has also been used in Masfjorden. Cod that are homozygote at a certain locus, PGI-1 * 30, resulted from cross breeding. Genetically tagged cod can be separated from wild cod because homozygote PGI-1 * 30 wild cod are very rare. The mass release in 1990 and 1991 contained 42 and 58 % genetically marked cod, respectively. The advantages with OTC- and genetical marking is low effort and cost associated with marking. The disadvantage is mainly that recaptures by sampling is necessary and the fish must be analyzed to determine whether marks are present. Sampling is laborious and expensive. OTC is also an antibiotic and thus should be used infrequently. To possibly avoid the latter problem we tested the colorant Alizarin because the potential harmful effects of this substance is unknown. Alizarin is used for mass marking of fish in Japan. Preliminary results with Alizarin applied to cod fry were promising. Large-scale marking with Alizarin was attempted the spring of 1992.

External Floy-tags are easily detectable by fishermen. Because of high price on these tags, they can only be used on a limited number of fish. Therefore, relatively few individuals in the mass releases were tagged with Floy-tags. The main purpose was to map the migratory patterns of released fish.

5.3 RELEASES

Reared juveniles were transported with tank boat from the production pond to Masfjorden. In 1985-1987 the fry were produced in the Hyltropoll in Austevoll, and in 1988-1991 in Parisvannet in Øygarden. The boat trip took 4-7 hours. At release sites the juvenile cod were dipped from the tank into a counting trough containing running water. After counting the fish were released though a tube (diameter 15 cm, length 6 m) which emerged at the sea surface (Fig. 3). To ensure that the released cod could rapidly seek shelter in the vegetation, the boat was maneuvered as close to shore as possible, and the tube was then directed towards shore.

5.4 ESTIMATION OF POPULATION PARAMETERS FOR COD

The time-series of data for the cod population in Masfjorden is too short to provide good estimates by means of traditional methods such as, for instance VPA (Virtual Population Analysis). We have used a combination of other methods for the years 1986-89: Catch per unit of effort from the sampling was

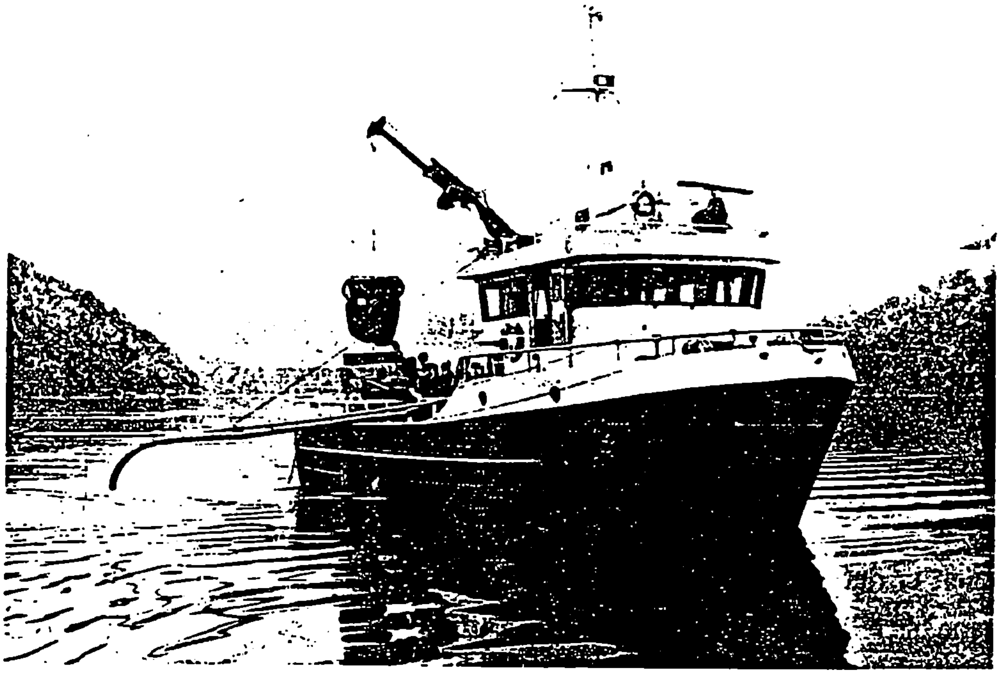


Fig. 3. Release of juvenile cod from the tank boat "Max" in Masfjorden. Cod are released though the tube on starboard side as the tube is lowered to the surface.

combined with mark-recapture data, plus data from fishermen's catch records. This method was based on two assumptions: that the net groups captured 1-group and older cod non-selectively; and that the net groups captured a constant proportion of each age-group each year (catchability coefficient is constant). For further details see SALVANES and ULLTANG (1992).

5.5 STOMACH ANALYSIS

Stomachs of cod, saithe, pollock and poor-cod from net samples were preserved in 6% neutralized formalin or frozen. The prey in each stomach were identified to lowest possible taxon, and divided into size groups within each taxon. Weight and numbers were recorded for each size group. The wet weight was determined after blotting on filter paper.

5.6. CAPTURE OF THE PREY OF COD

Small fishes in the kelp zone are important prey for cod in Masfjorden. Beach seine has traditionally been used to collect littoral fishes in Norway. The disadvantage with this method is that the seine often gets stuck on the bottom, and one has to pick a suitable location, not too steep or slippery, to land the seine on. Thus it is difficult to estimate the total water volume swept. A large proportion of the beach area around Masfjorden were too steep, and thus unsuitable for beach seine sampling. We therefore developed a "drop seine" to quantify small fishes in the kelp zone (FOSSÅ 1989). This gear is basically a seine, 4 x 4 m, tied up onto a floating frame. A sample can be taken by releasing the seine. A heavy chain at the base of the seine will pull it down to the bottom. In this manner it is possible to sample a known water mass and bottom area enclosed by the seine.

By means of this "drop seine" it was possible to obtain samples from the kelp zone along the entire fjord. However, routine collections were taken by beach seine since this gear was easier to handle. The results from the "drop seine" were used to calibrate the beach seine catches.

5.7 SIMULATION MODELS

Simulation models are mathematical models of the most important processes in the system investigated, and represent a supplement to field- and laboratory research. In the laboratory one can study a few processes closely, all other variation being eliminated. In field research one measures the most important components in a system, but it is impossible to cover time and space aspects. Complex ecosystems can therefore not be fully described by means of field- or laboratory studies, and a mathematical model therefore become a useful supplement. If the equations in the model describe the most important processes well, such a model may be used to investigate the effect of changes in parts of the system on the rest of the system. This makes it possible to study changes which has not yet occurred, which is often much cheaper than large-scale field projects. An ecosystem model can, for instance, elucidate the effect of changing currents in the fjord on production of cod and their prey, and simulation of alternative release methods may determine the effect of different releasing regimes on survival and growth of the stocked fish. The value of such a model, however, is strongly dependent on how well it mimics reality.

I addition to elucidate different scenarios, models are needed to develop sensitivity analyses. These show how sensitive the system is to changes, and at the same time indicate what precision is needed in measurements, which is a concern for both scientists and managers. The more sensitive the system is to changes in the numerical value of a component, the more resources should be allocated to measuring this variable.

Similarly, sensitivity analyses can predict whether known or assumed changes will have a significant effect on the system.

5.7.1 ECOLOGICAL MODELING OF MASFJORDEN

The ecological simulation models are programmed in FORTRAN-77, The model is run on a UNIX working station. The state variables in the model are phytoplankton, zooplankton, gobiids, wrasses, benthos and different year-classes of codfishes. The starting values for the state variables are obtained from Masfjorden, except for benthos which are obtained form the literature. Parameter values of the consumption for cod are based on experimental growth studies conducted as part of the Masfjord project. The first version includes the processes from phytoplankton to 0-group cod (GISKE *et al.* 1991), whereas en expanded model includes several age-groups of cod, and their main prey species (SALVANES *et al.* 1992).

5.7.2. RELEASE STRATEGY AND MANAGEMENT

As modeling tool to analyze release strategy and management of cod, we used a dynamic modeling program, STELLA ® II v. 1.0 for Macintosh (FOSSÅ and NORDEIDE 1991). The parameter values used in this model were obtained from the results of releases in Masfjorden and in Heimarkspollen in Austevoll. The releases in Austevoll were conducted by the Institute of Marine Research.

6. RESULTS AND DISCUSSION

6.1 THE FISH FAUNA IN MASFJORDEN

In total 71 species were registered (SALVANES *et al.* 1991). Eleven species dominated; three species of gobiids, four cod species, and four wrasses (Table 1). Of these species, cod, saithe and pollock are commercially important, cod being the most valuable.

Table. 1. Dominating fish species in Masfjorden before mass releases of cod. The catches were obtained by beach seine and gill nets from October 1985 to September 1987.

A. Beach seine 0-5 m depth	**Numbers (%)**
Gobiidae (gobiids)	
Two-spotted goby (*Gobiusculus flavescens*)	79.1
Painted goby (*Pomatoschistus pictus*)	8.8
Sand goby (*Pomatoschistus minutus*)	7.8
B. Net 5-20 m depth	
Gadidae (codfishes)	
Pollock (*Pollachius virens*)	16.7
Poor-cod (*Trisopterus minutus*)	16.1
Saithe (*Pollachius pollachius*)	9.4
Cod (*Gadus morhua*)	5.4
Labridae (wrasses)	
Cuckoo wrasse (*Labrus bimaculatus*)	12.9
Small-mouthed wrasse (*Centrolabrus exoletus*)	11.3
Ballan wrasse (*Labrus bergylta*)	9.7
Goldsinny-wrasse (*Ctenolabrus rupestris*)	6.6

6.2 COD

The general relationships between different parameters in a fish population are shown in Fig. 4. A population decreases in numbers by natural mortality, fishing morality, and emigration. Increase in biomass results from recruitment, growth of individuals, and immigration. One of the main goals of this research was to quantify population size, age composition, recruitment, growth and mortality for cod and other species before and after mass releases of juvenile cod.

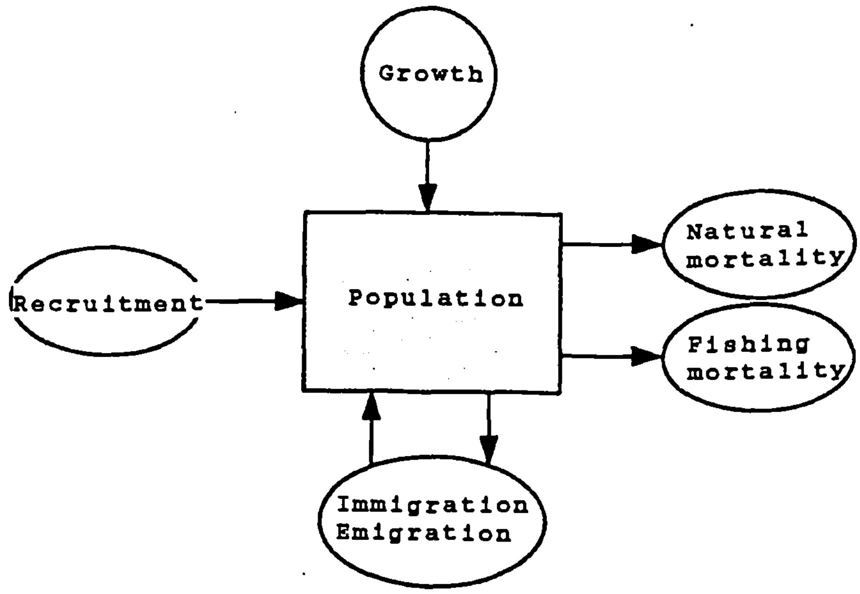


Fig. 4. The dynamics of an exploited fish stock. Modified from Ricker (1975).

6.2.1 RELEASE AND RECAPTURE

Nine groups of pond-reared cod (2,800-9,200 individuals) have been marked with Floy-tags and released during the period of 1985-1991 (Table 2). Mass releases (27,000-178,000 individuals) were performed in 1988 and the three subsequent years. In addition, wild cod were captured, tagged, and released in seven groups. Percentage recaptured varied from 1.4 to 10.7 for release groups of pond-produced cod (Fig. 5). Recaptures, expressed as weight per released individual, varied between 10 and 60 g (Table 3). Recaptures measured as kg per released kg, were between 0.23 and 0.96. Thus, we got less biomass back than was initially released. The fishing pattern in the fjord, with recreational fishermen catching many small fish, is probably one of the reasons for the low recapture expressed as biomass. The variation in size at time of release and growth during the period after release probably explains a large proportion of the variation in percent recapture between groups.

Recapture as a function of cod size at time of release

Release groups P87, P88V and P89V, had the largest mean length when released (20.1-25.3 cm) (Table 2) and gave significantly higher recaptures than the other groups, 10.2, 10.7 and 9.5 %, respectively (Fig. 5). Groups P86, P88H and P89H, released during the autumn, were small (17.6-20.4 cm) and had lower recapture percentages, 3.7, 3.4 and 1.4, respectively. Individuals from the 1988 and 1989 year-classes were released both during the autumn as 0-groups (P88H and P89H) and during the spring as 1-group (P88V and P89V). Mean length of cod released during spring was about 5 cm longer than those released during the autumn, and percentage recaptured was more than three times greater for the spring releases. Mean length

Table 2. Pond-produced and wild cod released in the release area in Masfjorden (U), in the control area (K) and in Austfjorden (Au). OCT = oxytetracycline.

Name	Month and year	Location	Numbers released	Mean length (cm)	**Method of marking**
Pond-produced					
P85	Nov 1985	U,K	3 331	18.1	Floy
P86	Dec 1986	U,K	2 779	17.6	Floy
P87	Nov 1987	U	7 026	20.1	Floy, OTC
P88S	Aug 1988	U	82 500	11.6	OTC
P88H	Sep-Nov 88	U,K	8 815	18.5-20.4	Floy, OTC
P88V	Apr 1989	U	1 944	25.3	Floy
P89S	Sep 1989	U	61 300	15.6	OTC
P89H	Nov 1989	U	9 188	19.8	Floy, OTC
P89V	Apr 1990	U	4 950	23.9	Floy
P90S	Oct 1990	U	26 760	17.1	OTC, Genetical
P90H	Nov 1990	U	4 109	22.1	Floy, OTC, Genetical
P91S	Aug 1991	K	178 000	9.4	OTC
P91H	Oct 1991	K	6 598	20.1	Floy, OTC, Genetical
Wild					
V873	Mar 1987	Au	87	67.8	Floy
V874	Mar 1987	K	60	41.5	Floy
V87	Mar 1987	U	103	50.0	Floy
V87S	Apr-Oct 87	U	186	40.1	Floy
V88	Feb 1988	U	155	65.4	Floy
V883	Feb 1988	Au	278	56.1	Floy
V90	Aug 1990	U	903	43.2	Floy
V91	Sep 1991	U	428	46.2	Floy

Table 3. Recapture of each release group when all individuals are included, and when only fish above the legal size (> 34 cm) are included. Catches until 31 December are included. P88H = pond-produced in the autumn of 1988, V = spring.

	Release		**Recapture**			
Release	Numbers	Biomass (kg)	Biomass total (kg)	Biomass individuals >34 cm	Harvest as g per released individual	Harvest as g per kg released
P85	3 331	178	134	116	40	750
P86	2 779	140	68	63	20	490
P87	7 219	351	337	250	50	960
P88H	8 248	451	102	67	10	230
P88V	1 944	297	116	89	60	390

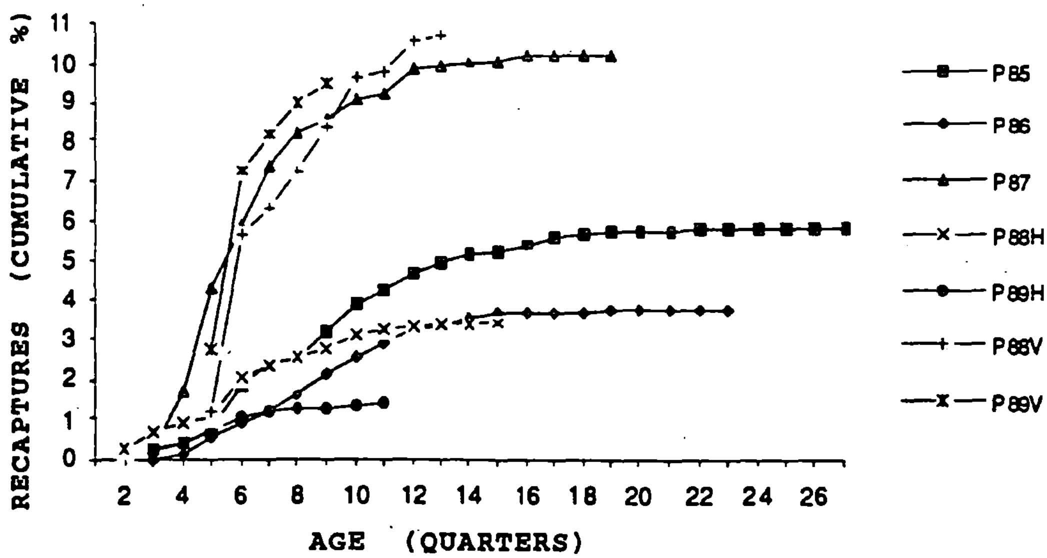


Fig. 5. Recaptures of Floy-tagged reared cod. (P88H) pond-produced and released in autumn 1988, (V) spring.

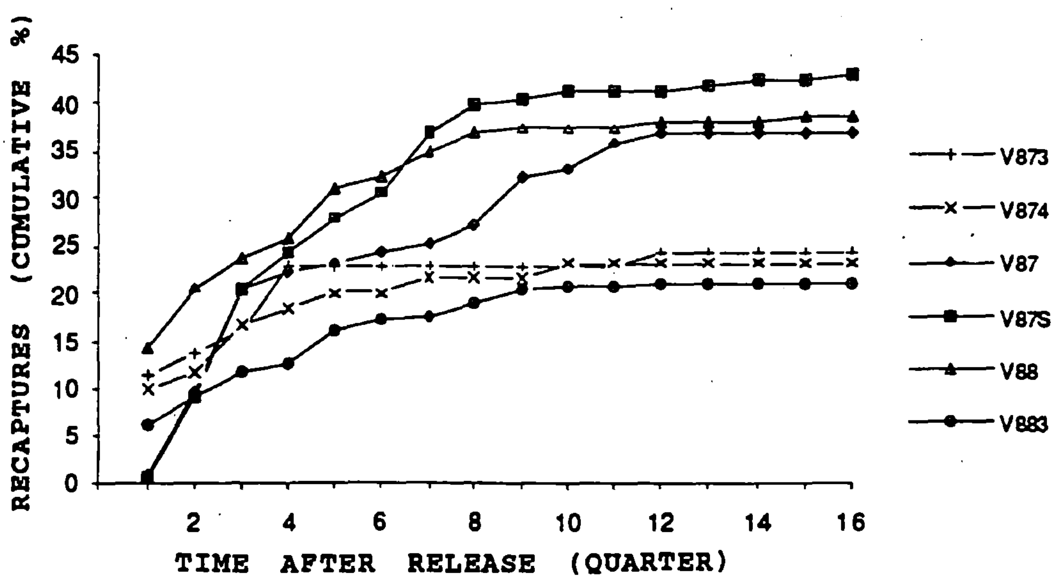


Fig. 6. Recaptures of Floy-tagged wild cod in Masfjorden.

at time of release was much longer for wild cod (41.5-67.8 cm) than for pond-produced cod (17.6-25.3 cm) (Table 2). Percent recapture was higher for wild cod (21-43 %) than for poll-produced cod (1.4-10.7 %) (Fig. 6). These results indicate that size at time of release is important for survival and recapture of cod, as has previously been shown by SVÅSAND and KRISTIANSEN (1990a). Fig. 6 also shows that recaptures in Masfjorden (three upper curves) were higher than in the control area (three lower curves). This may possibly be explained by higher survival in Masfjorden, higher frequency of reporting and higher fishing effort. It is difficult to say which of these factors are most important based on our current information.

The importance of food availability for releases

Of the groups which were released during the autumn, and therefore had approximately the same mean length at time of release, the group released in November 1987 (P87) had particularly high recapture percentage (Fig. 5). The period from spring 1987 though the following one and a half year was characterized by good food availability and rapid growth for cod. Autumn-releases 1986 (P86), 1988 (P88H) and 1989 (P89H), however, occurred during periods of poor food availability and slow growth. This shows the importance of timing of the release and growth conditions in the fjord for the recapture percentage of stocked cod. Size at release and densities of cod also affected survival of released cod in Austevoll (SVÅSAND and KRISTIANSEN 1990a). Most recaptures were taken within 2 years after release (Fig. 5 and 6). Cod younger than 2 years are of value for recreational fishermen, but has little value in the commercial fishery.

6.2.2 MIGRATION

Recaptures reported by recreational fishermen and local commercial fishermen show that 89-90 % of recaptures from the four Floy-tagged groups, released in Masfjorden in 1988 and 1989, were recaptured within Masfjorden (Table 4). Recaptures of Floy-tagged pond-produced cod released in Masfjorden in 1985, 1986 and 1987 were 93.2, 94.5 and 87.0 %, respectively (SALVANES and ULLTANG 1992). There is some tendency for fish to be caught outside Masfjorden as they grow older. This applies to all releases (Table 4). During sampling, 63, 16, 26 and 39 individuals were recaptured from the four groups released in 1988 and 1989. Of the respective fish, 1, 1, 0 and 1 were recaptured in the control area. Two individuals from the mass releases, P88S and P89S, were recaptured in the control area. This indicates that most of the pond-produced cod remained in Masfjorden. Because of low recaptures of sexually mature cod, it is difficult to say to which extent they emigrate from Masfjorden after reaching maturity. Mature wild cod, caught during spawning at the spawning areas in Masfjorden and adjacent fjords, migrated more than pond-produced cod and wild cod outside the spawning period (NORDEIDE and SALVANES 1988). These migratory individuals probably consist of cod from the outer fjord- and coastal areas, and are fish that migrate into the fjords to spawn and then leave after spawning.

No significant differences were found in the migratory patterns of pond-produced cod and wild cod in Austevoll (SVÅSAND 1990; SVÅSAND and KRISTIANSEN 1990b). Most studies conclude that juvenile cod are stationary (DAHL 1906; LØVERSEN 1946; SVÅSAND 1990; SVÅSAND and KRISTIANSEN 1990 b). Mature coastal cod may migrate longer distances (HYLEN 1964; JAKOBSEN 1987), but can also be stationary (SVÅSAND and KRISTIANSEN 1990b).

Table 4. Recaptured pond-produced cod, with Floy-tags, from the release area (U), the control area (K) and other sites (A). Recaptured cod from recreational and commercial fishermen are included until 1 May 1992. P88H = pond-produced autumn of 1988, V = spring. Data from the releases are in Table 2.

Year and Quarter		Released groups and release sites											
		P88H			P88V			P89H			P89V		
		U	K	A	U	K	A	U	K	A	U	K	A
1988	3	4	0	0									
1988	4	16	0	0									
1989	1	4	0	0									
1989	2	15	0	0	15	2	0						
1989	3	77	0	0	71	1	3						
1989	4	22	1	0	16	0	1	5	0	0			
1990	1	17	0	2	10	1	3	7	0	0	2	0	0
1990	2	20	0	0	21	0	0	22	0	0	112	0	0
1990	3	25	0	1	23	0	0	37	1	0	203	3	1
1990	4	11	0	1	3	0	0	5	1	0	39	0	0
1991	1	2	1	4	9	0	6	6	1	0	34	5	0
1991	2	2	0	1	0	1	1	2	1	0	24	0	0
1991	3	1	0	0	2	1	1	7	1	0	33	3	1
1991	4	4	0	0	1	0	0	4	0	0	18	0	0
Total number		220	2	8	171	6	15	95	5	0	465	11	2
Tot.(%)		95.6	0.9	3.5	89.1	3.1	7.8	95.0	5.0	0	97.3	2.3	0.4

6.2.3 YEAR-CLASS STRENGTH AND PROPORTION OF POND-PRODUCED COD

Cod recruited to the sampling fishery in January as yearlings. The yearling age-classes from 1984 and 1987 (about 100,000 individuals) were about ten times stronger than year-classes from 1985 and 1986 (Tables 5-7). The year-class from 1988 was about three times stronger than the weakest ones. In August 1988 this year-class was estimated as > 180,000. This indicates heavy mortality of 0-group cod this year.

The year-classes of 1989 and 1990 were not quantified as in the previous years. However, the catch per unit of effort still shows that yearling fish from the 1989 and 1990 year-classes had similar strength as the 1988 year-class (Fig. 7). Pond-produced cod contributed 42, 89 and >50 % of the respective year-classes of 1988, 1989 and 1990.

Table 5. Estimated number of recruited year-classes of cod during the period 1984-1989, a = age, - = estimate not available.

a	1984	1985	1986	1987	1988	1989
1	21 112	101 336	9 841	13 016	100 952	29 524
2	-	9 392	45 080	5 397	6 032	35 239
3+	-	-	6 666	20 000	4 761	4 444
Total	-	-	61 587	38 413	111 745	69 207

Table 6. Estimated biomass in tonnes of recruited year-classes of cod during the period 1984-1989, a = age, - = estimate not available.

a	1984	1985	1986	1987	1988	1989
1	4.28	20.52	1.99	2.64	20.44	5.97
2	-	4.37	20.96	2.51	2.80	16.39
3+	-	-	7.27	21.79	5.19	4.84
Total	-	-	30.22	26.94	28.43	27.74

Table 7. Year-class strength of wild and pond-produced cod of the year-classes 1983-1989 in the release area. The year-class strengths were estimated as 1-group cod. Data on year-class strength are from SALVANES and ULLTANG (1992).

Year-class	Numbers	Pond-produced cod in % of total no.
1983	21 100	0
1984	101 000	0
1985	9 800	< 1
1986	13 000	< 1
1987	101 000	2
1988	29 500	45

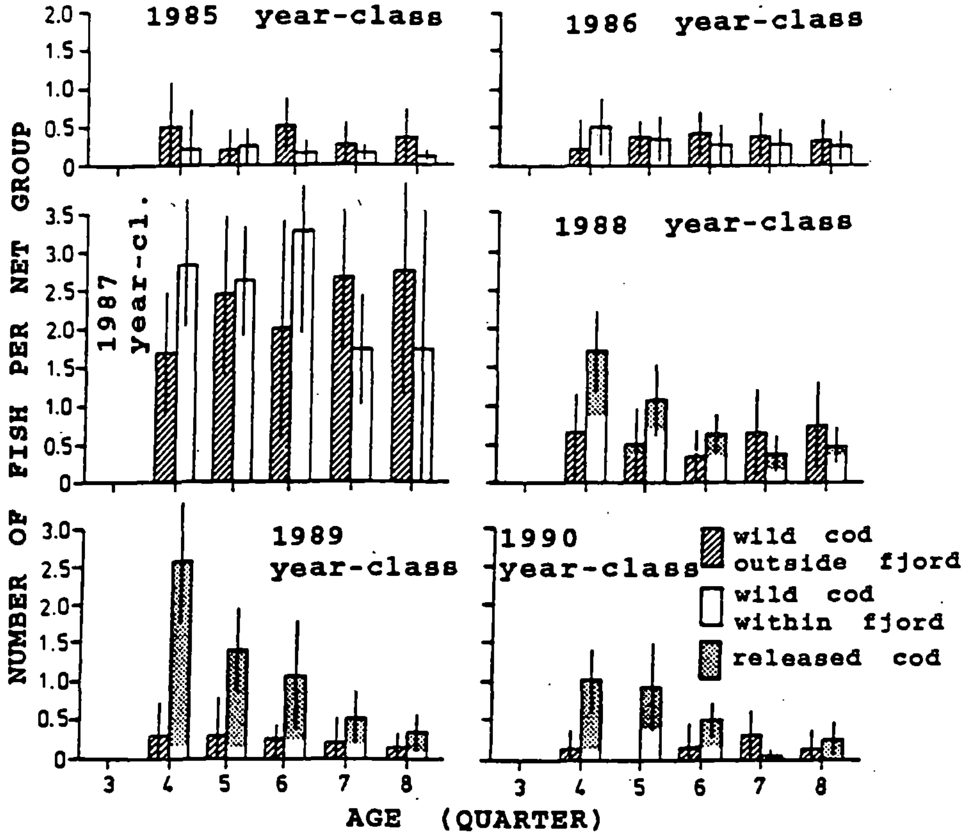


Fig. 7. Mean catches of year-classes of cod per three nets. Shaded bars show wild cod in control areas, blank bars show wild cod in release area, and dotted bars show cod reared from release area. Intervals showing ± 2 SE are calculated after pooling of wild and reared cod.

It was either the 1- or 2-group cod that dominated in numbers and weight, except for the year 1987 when age-3+ cod were most abundant (Table 6). Total biomass was approximately equal all years (27-30 tonnes), but a longer time-series is needed to determine whether the population is stable. Table 5 and 6 show that neither numbers nor biomass of 1-group cod in 1989 were of similar magnitude as the rich year-classes of 1984 and 1987, at the same age, even though a large number of 0-group cod were released the previous years. Possible causes are discussed below.

6.2.4 EXPLOITATION

Catches of cod in Masfjorden were large in 1988 and 1989 (Table 8). The strong 1987 year-class dominated the catches.

Table 8. Estimated catches of cod. Numbers (N x 1000) and weight (B tonne) for different year-classes.

	1986		1987		1988		1989	
Year-class	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
1	0.09	0.02	0.24	0.05	5.65	1.14	2.59	0.53
2	2.36	1.10	0.25	0.12	0.54	0.25	11.93	5.55
3	0.37	0.31	0.77	0.64	0.81	0.67	0.64	0.53
4+	2.67	4.14	1.60	2.48	1.97	3.06	1.91	2.98
Total	5.49	5.58	2.86	3.29	8.97	5.12	17.07	9.59

6.2.5 MORTALITY

Total annual mortality, estimated for cod in Masfjorden (Table 9), corresponded to similar estimated of cod in Austevoll (SVÅSAND and KRISTIANSEN 1990a). However, fishing mortality (F) seemed to be far less in Masfjorden than in Austevoll. In Masfjorden $F_{2/3}$ were estimated as 0.08-0.17 annually during the period of 1986-1989 (Table 10), whereas estimates of $F_{2/3}$ from Austevoll were 0.40-0.76 (SVÅSAND and KRISTIANSEN 1990a).

Table 9. Estimated yearly instantaneous total mortality for age group *a/a+1* from the middle of year *t* until the middle of year *t+1*.

t/t+1 a/a+1	1986/1987	1987/1988	1988/1989	Mean
1/2	0.60	0.77	1.05	0.81
2/3	0.97	1.04	1.56	1.19
3+/4+	0.85	1.95	0.41	1.07

Table 10. Estimated instantaneous fishing mortality for age-group *a/a+1* from the middle of year *t* until the middle of year *t+1*.

t/t+1 a/a+1	1986/1987	1987/1988	1988/1989	Mean
1/2	0.05	0.04	0.11	0.07
2/3	0.08	0.20	0.17	0.15
3+/4+	0.43	0.26	-	0.35

The difference between total mortality and fishing mortality in Table 9 and 19 indicates that the natural mortality was high for all age-groups. Even for older fish the natural mortality was higher than what has been reported elsewhere. This may be because catches in the recreational fishery have been underestimated, and that a large proportion becomes unavailable to the fishery because they may move out of the habitats fished.

Released cod are probably subject to heavier predation during the first days and weeks after being released than at a later time (NORDEIDE and SALVANES 1991). The reasons for this may be stress during transport and release operations, new and unfamiliar surroundings, densities being to large after releases, or differential selection pressure in the production pond as compared to the fjord. In laboratory tests, pond-produced cod were more cautious towards a predator than wild cod, although this may not necessarily explain the greater mortality of pond-produced cod immediately after release (NORDEIDE and SVÅSAND 1990). The proportion wild to released cod of the 1988 year-class did not decrease significantly from the age of 4 to 9 quarters (NORDEIDE *et al.* 1992). This indicated that mortality of wild and released cod were not different after 1/2 year post release. These results may indicate that recently released pond-produced cod need some days or weeks to acclimate themselves to new and unfamiliar surroundings in the fjord.

The number of cod captured per three nets were approximately equal in the release and control areas for the 1985, 1986 and 1987 year-classes (Fig. 7). Mass releases in 1988, 1989 and 1990 resulted in increased catches of the respective year-classes, and resulted in significantly larger catches in the release area than in the control area. Concerning the 1988 year-class this only applies to cod that were younger than five quarters old, and for the 1989 year-class it applied to cod less than 6 quarters old. There were only small differences in catches between areas during the subsequent periods. The mean catches from the weak year-classes from 1985 and 1986, and from the strong 1987 year-class, only decreased slightly from ages 4-8 quarters (Fig. 7). Catches of the 1988 and 1989 year-classes, however, did decrease during this age interval.

Survival of the first mass release (P88S), released in August 1988 and the subsequent eight months, was estimated to 17 percent. Of the cod released in Austevoll as 0- and 1-group, 13 and 32 percent, respectively, survived until they became two years old (SVÅSAND and KRISTIANSEN 1990a). Thus, survival was lower for the 1988 year-class in Masfjorden than for the releases in Austevoll. Ricker's-two release method was used to obtain these estimates (RICKER 1958).

6.2.6 DENSITY

The amount of one and two-year old cod was relatively high in 1986, 1988 and 1989, and low in 1987, 1990 and 1991 (Fig. 8). The mean catch of cod in 1986 was higher in the control area than in the release area. There were no significant differences between the two areas from 1987 to 1989. During the first halves of 1990 and 1991, densities of 1- and 2-group cod were greater within the fjord than outside it. These differences were caused by the mass releases in 1989 and 1990.

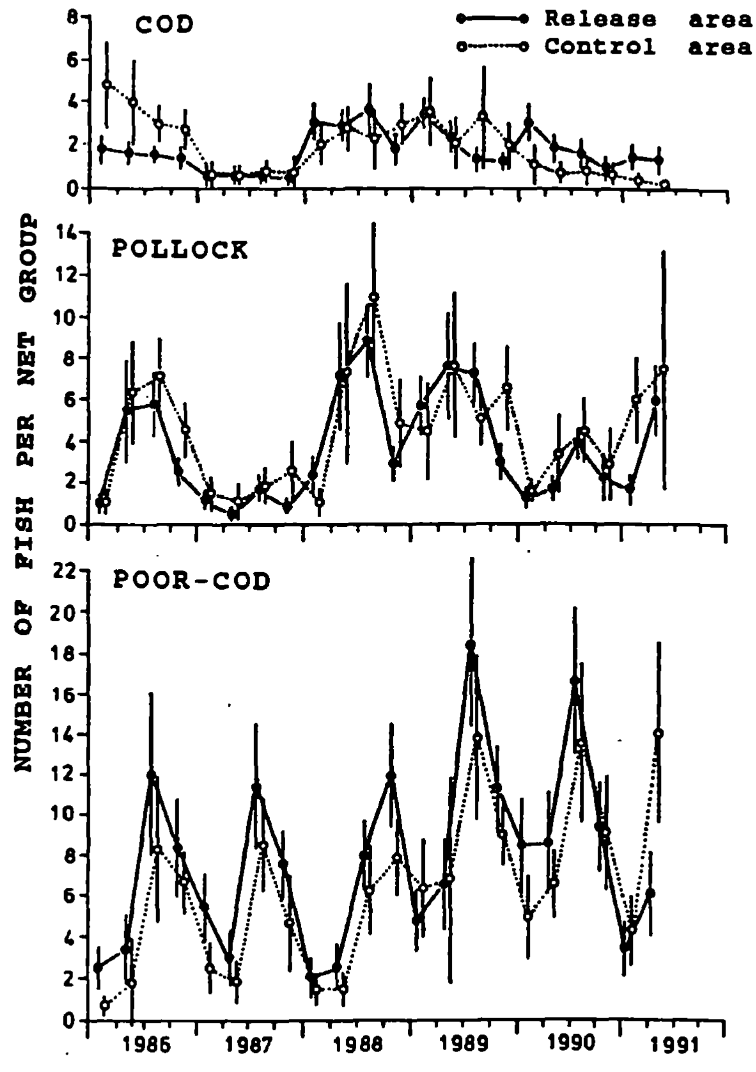


Fig. 8. Mean (± 2 SE) number of cod, pollock and poor-cod caught per three nets 1986-1991. The number of 1- and 2-year old fish are shown for cod and pollock, whereas all age-groups of poor-cod are included.

6.2.7 GROWTH

Inter-annual variation

As one and two year old fish, the 1987 year-class grew faster than the other year-classes (Table 11). The 1988 year-class grew very well during the summer and autumn 1988. Within this period, food availability (amount of gobiids) was the largest recorded. Mean condition factor (gutted weight x 100/length^3) of the 1984 year-class of cod in the release area was about 0.85 in 1986 (Fig. 9). The condition factor of the 1987 year-class of cod in the fjord was >1.0 in the third quarter of 1988, but it subsequently declined to about 0.85 in 1989 and 1990 (Fig. 9). Mean condition factor of cod in the control area showed a similar pattern as within Masfjorden, although with less variation. Mean liver index of cod from the 1987 year-class was high in 1988, but declined to a low level in 1989 (Fig. 10). For the 1988 year-class the index was low in 1989 and 1990.

Table 11. Growth of wild and released cod estimated by linear regressions. Individuals 270 to 800 days old are included. Release area (U), control area (K).

Year-class	Location	Wild or pond-produced	Numbers	Growth (mm/day)
1985	U	Vill	30	0.30
1985	K	Vill	32	0.27
1987	U	Vill	510	0.40
1987	K	Vill	214	0.37
1988	U	Vill	129	0.25
1988	K	Vill	32	0.27
1988	U	Pollprod.	97	0.28
1989	U	Pollprod.	267	0.34

Comparison of growth in release and control areas

No significant differences were registered in the length growth of cod between the release and control areas ($p > 0.05$, ANCOVA). This was the case both before and after mass releases. Mean condition factors of the 1984 year-class were not significantly different in the release and control areas in 1986 and 1987 (Fig. 9). During the periods before and at the first mass release (third quarter 1988), the mean condition factor of the 1987 year-class was greatest in the release area. After this mass release no significant differences were detected. Mean liver indices of the 1987 year-class were not significantly different in the release and control areas, except for the third quarter of 1988 (Fig. 10).

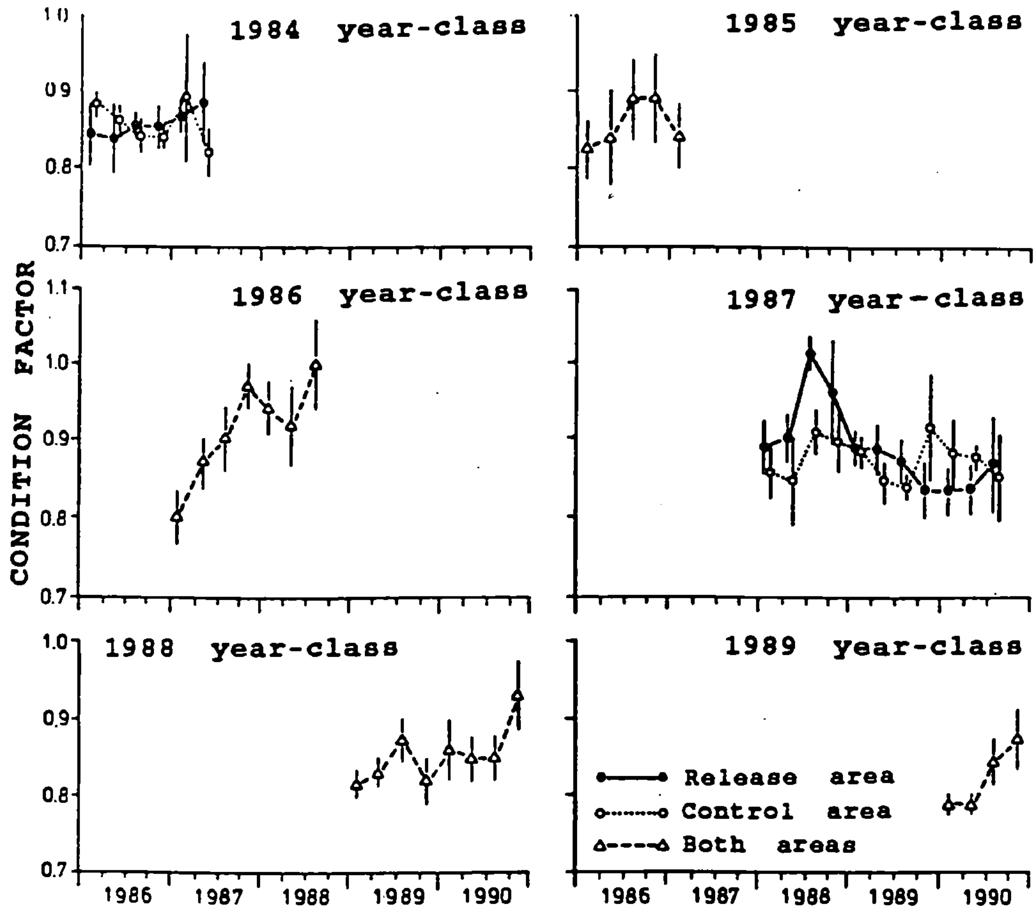


Fig. 9. Cod. Mean (± 2 SE) condition factor. For the rich 1984- and 1987 year-classes, the indices from release and control areas are shown separately, whereas the index from the other year-classes is based on pooled data.

Growth of pond-produced and wild cod of the 1988 year-class were not significantly different (NORDEIDE *et al.* 1992). Similar results were recorded at Austevoll (KRISTIANSEN and SVÅSAND 1990). The liver index was significantly higher for pond-produced cod than for wild cod, within the first two months after release (NORDEIDE and SALVANES 1991). The explanation for this is that the pond-produced cod were fed prior to release, with excess energy being stored in the liver. The liver index (liver weight x 100/gutted weight) of released cod decreased gradually, and within three-four months after release there were only small differences in liver indices between wild and released cod.

6.3 POLLOCK AND POOR-COD

Poor-cod and pollock will to a large extent eat the same prey and live in the same habitats as juvenile cod (SALVANES *et al.* 1991). These species therefore are potential competitors to cod.

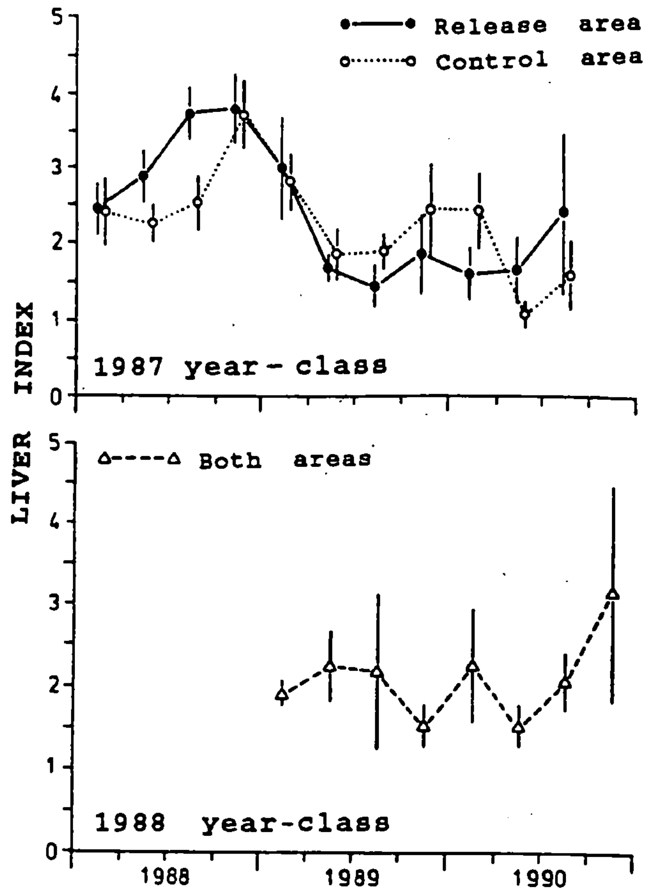


Fig. 10. Cod. Mean (± 2 SE) liver index. For the rich 1984- and 1987 year-classes, indices from release and control areas are shown separately, whereas the index from the other year-classes is based on pooled data.

6.3.1 DENSITY

One and two-year old pollock were about twice as abundant in catches as cod of the same age-groups (Fig. 8). There were few pollock in 1987 and 1990, but more were present in 1988 and 1989. Significant differences in catches between release and control areas were present only in two of the 22 quarters investigated. Estimated biomasses for the 1985, 1987, and 1988 year-classes of pollock have two peaks, the first during the autumn as 1-group, and the other during the autumn as 2-group (1988 year-class) or 3-group (1985 and 1987 year-classes) (Fig. 11). The catches of poor-cod varied more within a year than did catches of cod and pollock (Fig. 8). The catches were largest in the third quarters. Poor-cod were most abundant in 1989-91. The catches of poor-cod in release and control areas were only significantly different three of the 22 quarters.

6.3.2. GROWTH

Inter-annual variation

The mean length-at-age of the different age-classes of pollock varied little (Fig. 12). Any differences follows the general pattern of slow growth before third quarter of 1987, fast growth during the last part of 1987 until the forth quarter of 1988, and not just as fast thereafter. The condition factors of pollock and poor-cod (Figs. 13 and 14) adhere to the same

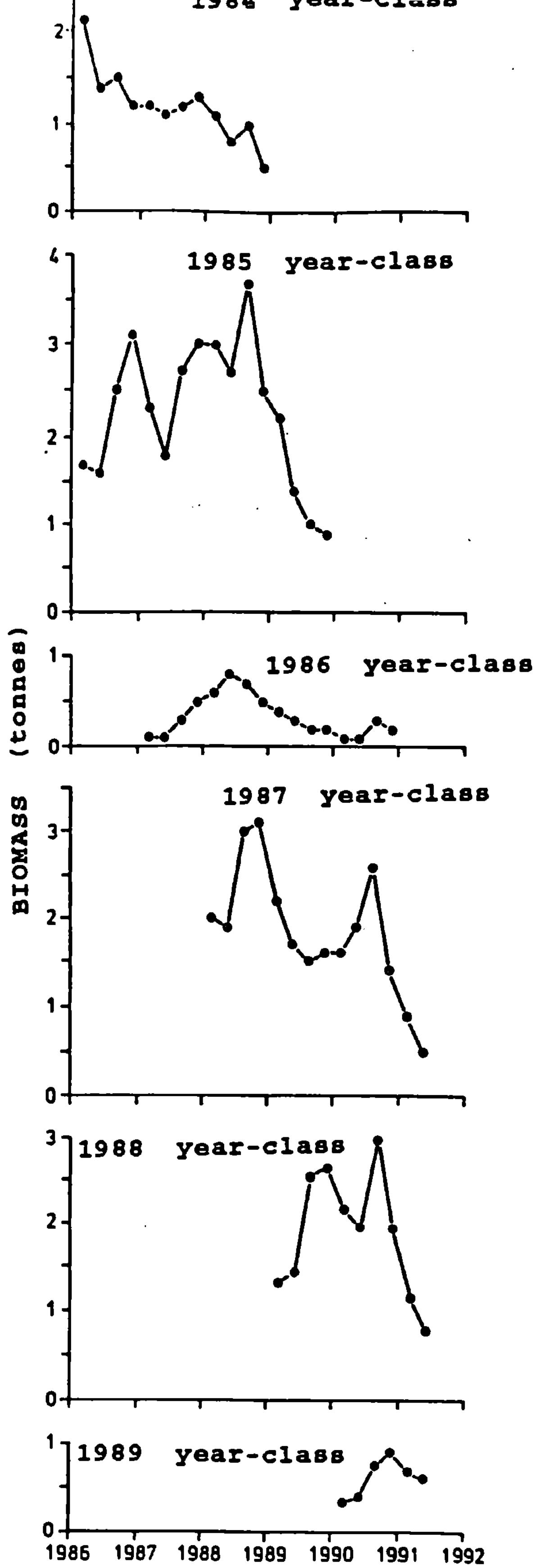


Fig. 11. The biomass of the year-classes 1984-1989 of pollock from January 1986 through June 1991, estimated by cohort analysis. The biomass is a combination of numbers and weight, and since the numbers here decline over time. Any increase in biomass is a result of increased individual growth.

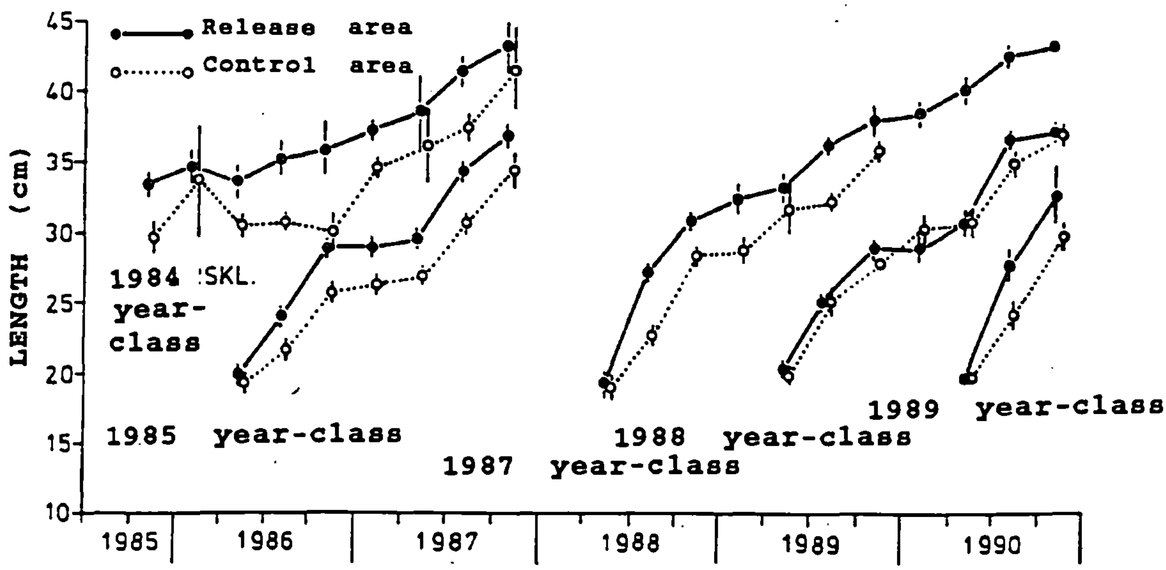


Fig. 12. Pollock. Mean length (± 2 SE) of five year-classes in the release and control areas.

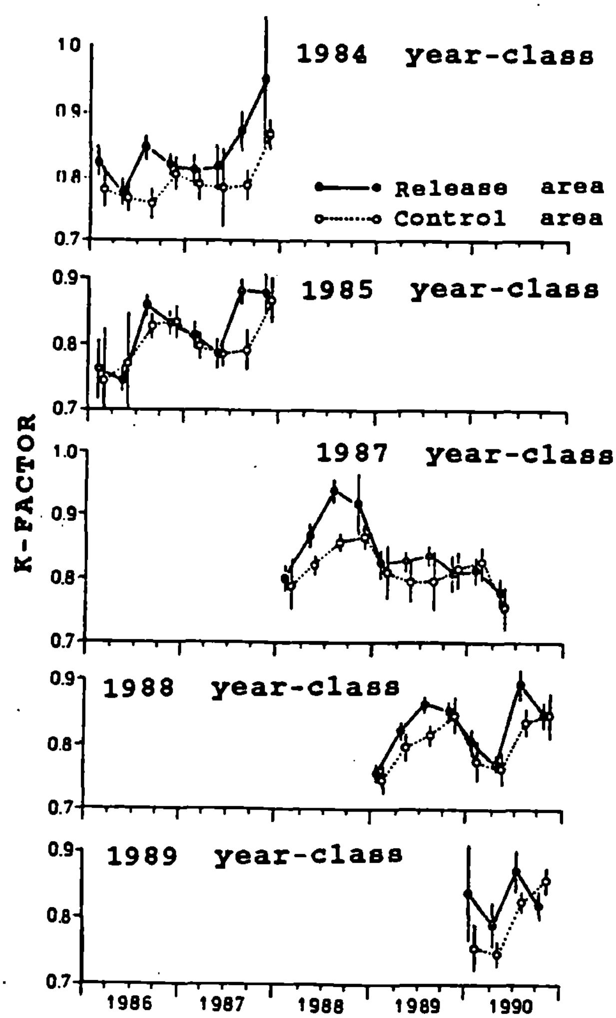


Fig. 13. Pollock. Mean condition factor (± 2 SE) of five year-classes in the release and control areas.

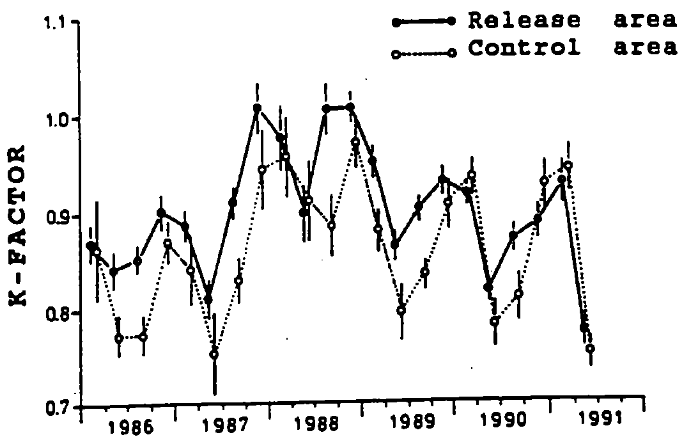


Fig. 14. Poor-cod. Mean (± 2 SE) condition factor for individuals of 17-24 cm length.

pattern, with relatively low values in 1986, high values from forth quarter of 1987 to forth quarter of 1988, and low values in 1989 and 1990.

Comparisons between release and control areas

The length of pollock was significantly higher in the release area than in the control area during most of the quarters for the 1984, 1985, 1987 and 1989 year-classes (Fig. 12). The exception was the 1988 year-class, for which the differences between areas were less. The condition factor was slightly higher in the control area for both pollock and poor-cod (Fig. 13 and 14). For pollock, the differences were significant during the third quarter most of the years, whereas they were not significant in the first and forth quarter. For poor-cod, the differences were significant during the third quarter each year, and also during the first three quarters of 1989. The liver index of the 1987 year-class of pollock was significantly higher in the release area than in the control area, in the second, third and forth quarter of 1988, and in the third quarter of 1989 and 1990 (Fig. 15).

6.4 THE EFFECT OF RELEASES ON CODFISHES

6.4.1 WILD COD

We could not detect differences in length growth between release and control areas, before or after mass releases (Table 11). Mean condition factor of the 1987 year-class was higher in the release area than in the control area in the period before the mass release (Fig. 9). Just before the first mass release the differences decreased, and after the second mass

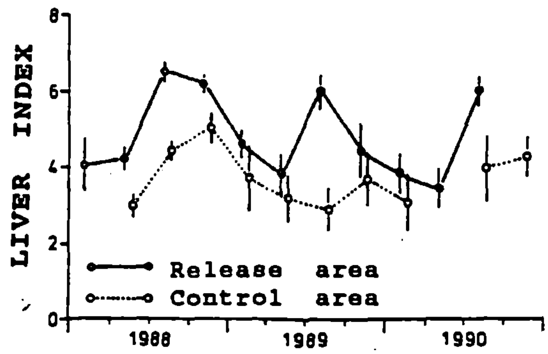


Fig. 15. Pollock. Mean (± 2 SE) liver index for the 1987 year-class.

release the mean condition factor of the 1987 year-class was higher in the control area then in the release area. However, the differences between areas were not significant, except from one quarter before the mass releases. Corresponding non-significant differences were also found for the liver index of the 1987 year-class of cod (Fig. 10). This indicates a slight reduction in condition factor and liver index of wild cod because of the releases.

6.4.2. POLLOCK

Lengths of year-classes 1984-87 were significantly longer in the release area than in the control area (Fig. 12). However, the differences in lengths of the 1988 year-class were not significant. Condition factors of year-classes 1987-88 largely adhere to the same pattern as cod, and we could not show any changes after releases (Fig. 13). The 1985 and 1987 year-classes show one peak in growth during the autumn of 1988, but the fast growth seemed to start before releases. Food availability during the autumn of 1988 was good, with abundant zooplankton, gobiids and wrasses. The 1988 year-class showed a growth peak during the autumn of 1989, whereas the 1987 year-class did not show a similar peak. As shown in Fig. 11, the growth varies considerably, and it is impossible to see whether it becomes faster or slower because of the releases. Both the 1985 and 1987 year-classes of pollock peaked in biomass as 1- and 3-group, respectively, just after releases of cod in 1988. The 1985 year-class may have preyed upon the juvenile cod and the growth may have become enhanced because of this.

6.4.3 POOR-COD

Poor cod follows the patter for cod and pollock, with mean condition factors being higher in the release than in the control area prior to mass releases. After releases the mean condition factor in the control area was higher than in the release area during some of the quarters, although these differences were not significant.

6.5 THE FOOD OF CODFISHES

Cod eat a broad spectrum of prey in Masfjorden (SALVANES *et al.* 1991). Cod younger than three years eat mostly crustaceans, gobiids and polychaetes. Crustaceans are important throughout the year, gobiids during the summer and autumn and polychaetes during winter. Larger cod also prey on crustaceans and gobiids, fish becoming increasingly important for larger cod. Gobiids, wrasses and codfishes are often eaten.

One and two-year old cod in two subsequent year-classes show large overlap in both type and size of prey taken during periods of low food availability in the fjord (NORDEIDE and FOSSÅ 1992). This indicates competition between subsequent year-classes of cod. The first days after release, pond-produced cod eat prey that are rarely taken by wild cod (NORDEIDE and SALVANES 1991). Prey choice of pond-produced cod then gradually becomes similar to that of wild cod (KRISTIANSEN and SVÅSAND 1992), and three months after release there are only small differences in choice of type and size of prey between pond-produced and wild cod (NORDEIDE and FOSSÅ 1992).

The most important interactions between the codfishes in Masfjorden are illustrated in Fig. 16. Cod are most important for sea ranching, but other species also compete with cod. This probably influences the production of cod. For instance, gobiids are well represented in the diets of all codfishes. FOSSÅ (1991) showed that when the biomass of two-spotted goby was highest, this prey comprised a larger proportion of the stomach contents of cod than when gobiid density was low. The proportion of gobiids decreased with increasing length of the predator, whereas the proportion of the larger fish species increased. Cod and pollock also eat a large proportion of wrasses, their younger conspecifics and other codfishes. Pollock and cod >45 cm eat wrasses throughout the year, except during the autumn when they prey maximally on cod (SALVANES *et al.* 1991). One may speculate whether large pollock and cod prefer juvenile cod in their diets even though wrasses are relatively important during the autumn.

6.6 THE PREY OF COD

6.6.1 PRODUCTION OF PREY

As mentioned, cod takes a variety of prey in Masfjorden, although some of these are very difficult to quantify, for instance galatheoids and crabs. To determine the development of prey populations after the release of cod, it was necessary to find organisms that were important prey for cod and at the same time were possible to quantify. The choice therefore became species of gobiids that fulfilled both requirements. Gobiids, especially the two-spotted goby which is very

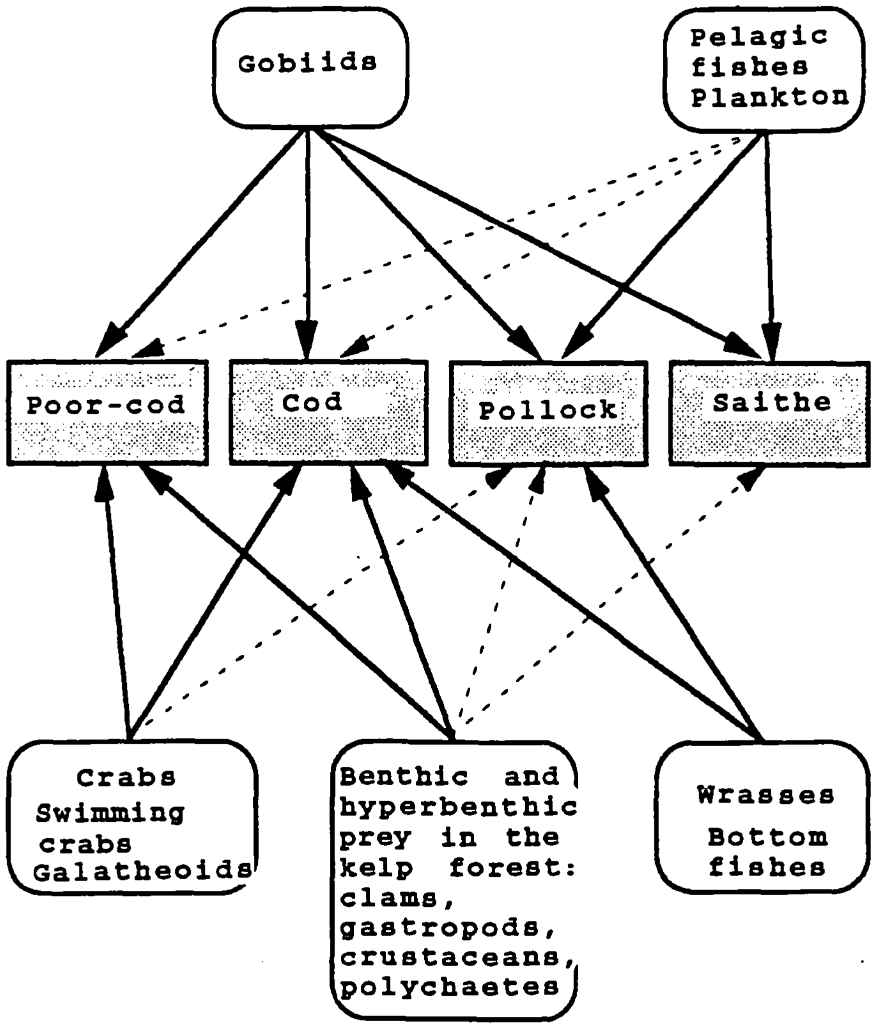
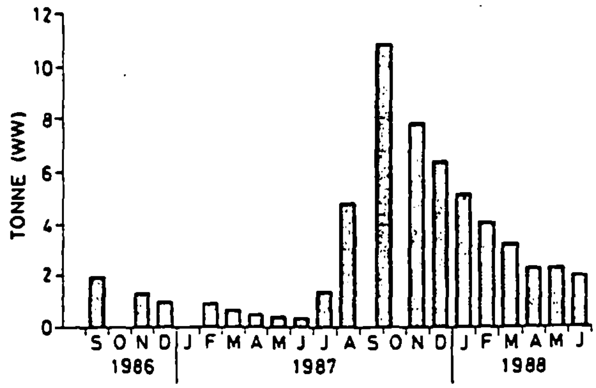


Fig. 16. Main trophic relations among the gadoids in Masfjorden.

abundant, also fitted because of one other reason. Zooplankton is the main food for all gobiids in Masfjorden. Thus we can couple an important component of the diet of cod to secondary production in the fjord. We have therefore emphasized analysis of the food-chain: *Zooplankton - two-spotted goby - cod.*

The years 1986 and 1987 are analyzed in detail by FOSSÅ (1991), and to describe parts of the fundamental findings regarding the ecosystem, we look at these years in particular. The two-spotted goby spawns during the spring. Early in the summer there are large concentrations of gobiids in the kelp beds. The juveniles remain there to prey on plankton and grow fast. The largest production occurs in July-September, and a maximum in biomass is reached in September-October (Fig. 17 and 19). One year-class will then decrease in numbers during winter and spring and totally disappears after spawning. There are large variations between years and between parts of the fjord. The observed production per meter shoreline in the inner part of the release area was 12 and 19 % of the production in the outer



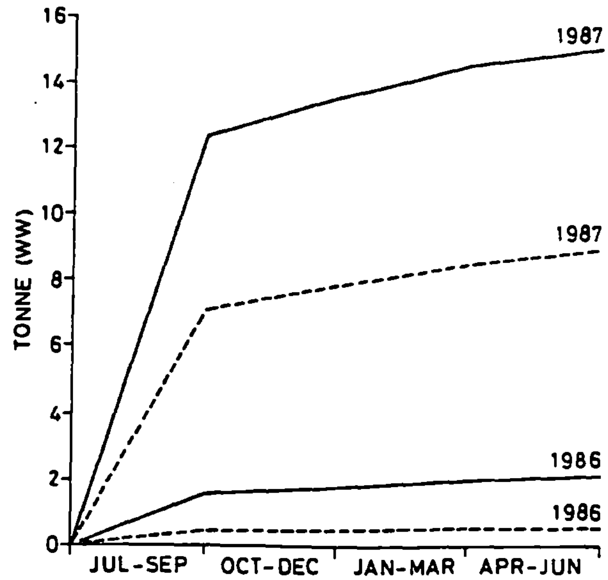


Fig. 17. *Gobiusculus flavescens.* Total biomass (tonne wet weight) for the 1986 and 1987 year-classes in the release area. The values are estimated form an exponential function.

Fig. 18. *Gobiusculus flavescens.* Cumulative total production (tonne wet weight) for the 1986 and 1987 year-classes in the inner (--) and outer (--) part of the release area in Masfjorden.

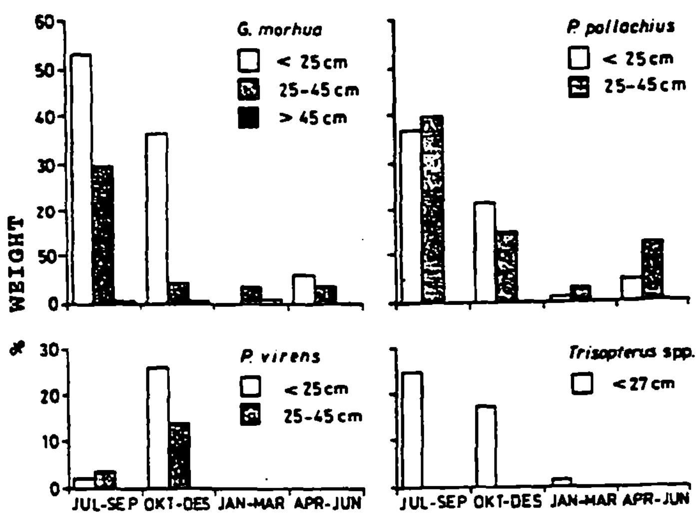


Fig. 19. Predation on *Gobiusculus flavescens* by codfishes in Masfjorden during the years 1985-1987. Vertical axis: *G. flavescens* as percentage weight of total stomach content.

part of the fjord in 1986 and 1987, respectively. Total productions in the inner and outer parts in 1986 were 14 and 23 %, respectively, as compared to 1987 (Table 12 and Fig. 18). The peak in biomass during the autumn is also reflected in the predation by the codfishes (Fig. 19). During the autumn the predation pressure on two-spotted gobiids is probably high since they school in dense, easily detectable, aggregations along the entire fjord at this time.

Table 12. *Gobiusculus flavescens.* Production (P in wet weight) in three different sub-areas of Masfjorden per m shoreline (P/m) and total production of a year-class (P tot.). The production is based on observed value and on estimates from an idealized curve function using the calculated daily instantaneous mortality rate and the abundance estimates from the starting and ending points of the observed year-class development.

Year-class	Inner and middle part of the release area (50 km)		Outer part of release area (22.5 km)		Control area (70 km)	
	P/m (g)	P tot. (tonnes)	P/m (g)	P tot. (tonnes)	P/m (g)	P tot. (tonnes)
1986						
Observed	12.6	0.6	90.3	2.0	90.3	6.3
Estimated	12.6	0.6	102.2	2.3	102.2	7.2
1987						
Observed	106.8	5.3	470.8	10.6	470.8	33.0
Estimated	180.0	9.0	671.1	15.1	671.1	47.0

The greater production in the outer part of the fjord we attribute to greater availability of zooplankton and more shallow areas with kelp in this area. Other species of prey that are dependent on zooplankton and kelp forest will probably also experiences greater production in the outer areas.

Table 13 shows the amounts of the different components of the food chain: *zooplankton - two-spotted goby - cod.* There seems to be a good link between zooplankton, two-spotted goby and 0-group cod, but the link between two-spotted goby and 1-group cod seems to be weaker. This may be because competition and predation affects this relationship. In 1985, there was little plankton and few 0-group cod. In 1986 there was little plankton and low production of two-spotted goby and 0-group cod. In 1987 the amount of zooplankton was large, the production of two-spotted goby was ten times higher than in the previous year, and this resulted in a very good year-class of cod. In 1988 there was lots of plankton and two-spotted gobies, and in August there was a considerable number of wild cod (180,000 individuals).

Table 13. Biomass of herbivore zooplankton in Masfjorden, production of two-spotted goby and estimated number of 0-group cod of the respective year-classes. AFDW = ash free dry weight, WW = wet weight.

Year	Herbivores (tonnes AFDW) 0-50 m	Herbivores (tonnes AFDW) whole water column	Two-spotted goby production (tonnes WW)	0-group cod (numbers)
1985				15 000
	Jun 16.0	32.0		(November)
	Oct 1.5	21.5		
1986			2.9	17 000
	Dec 4.1	22.4		(December)
1987			24.1	> 200 000
	Jan 2.0	27.5		(August)
	Mar 3.7	6.5		
	Apr 17.6	27.6		
	Apr 65.8	88.7		
	Mai 47.0	71.3		
	Jun 28.5	45.1		
	Jul 51.8	83.8		
	Sep 45.7	226.4		
	Dec 11.4	111.1		
1988			76.6	180 000
	Jan 3.2	36.1		(August)
	Apr 33.5	49.3		

6.6.2 LONG-TERM TRENDS IN PREY POPULATIONS

One of the objectives of the Masfjord project has been to determine the population trends of the prey. One might assume that some of the main prey of cod could have been subject to damaging effects if the predation pressure was increased over subsequent years by releasing cod. Fig. 20 shows the mean biomass per net haul of two-spotted goby in 1986-1991. An analysis of 1986-87 was undertaken in the previous paragraph. In 1988 the numbers increased tremendously when compared to 1987, whereas in the next year it varied at the same level as in 1986 and 1987. Based on the population trends of two-spotted goby, we can not positively identify any effects of cod releases on population numbers. In Masfjorden, the longevity of two-spotted goby is only 1.5 years, and the population is thus severely decimated every year. However, the species appears to have large enough reproductive potential to bounce back every year and can respond with high reproductive success if the environmental conditions are favorable. The release therefore does not appear to represent any danger for the populations in the fjord. Wrasses are also food for large cod. These fish vary in numbers, with a peak in 1988 as was the case for two-spotted goby (Fig. 21).

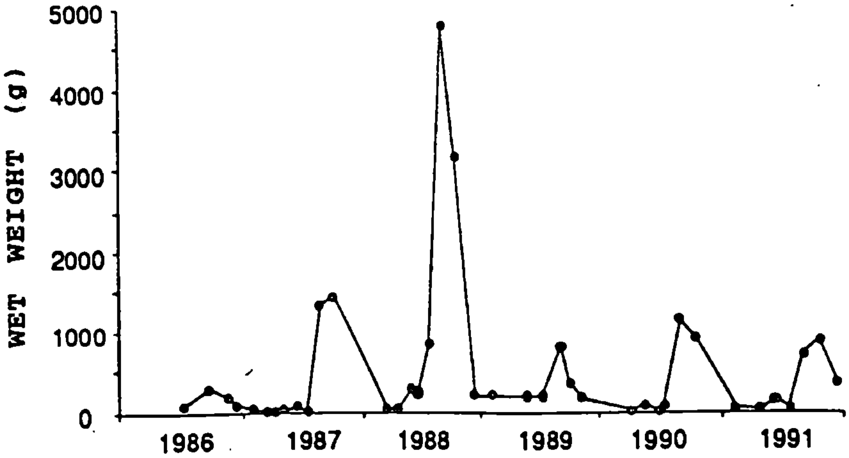


Fig. 20. *Gobiusculus flavescens.* Mean biomass in beach seine hauls in Masfjorden.

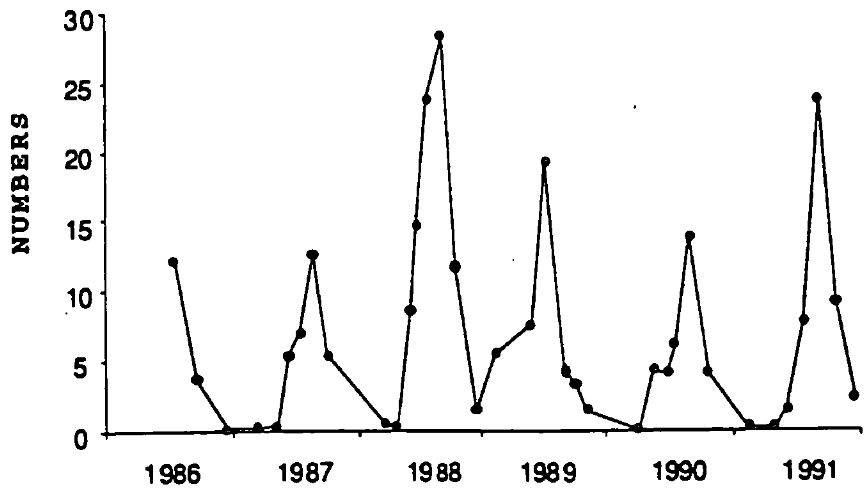


Fig. 21. Mean number of wrasses in beach seine hauls in Masfjorden.

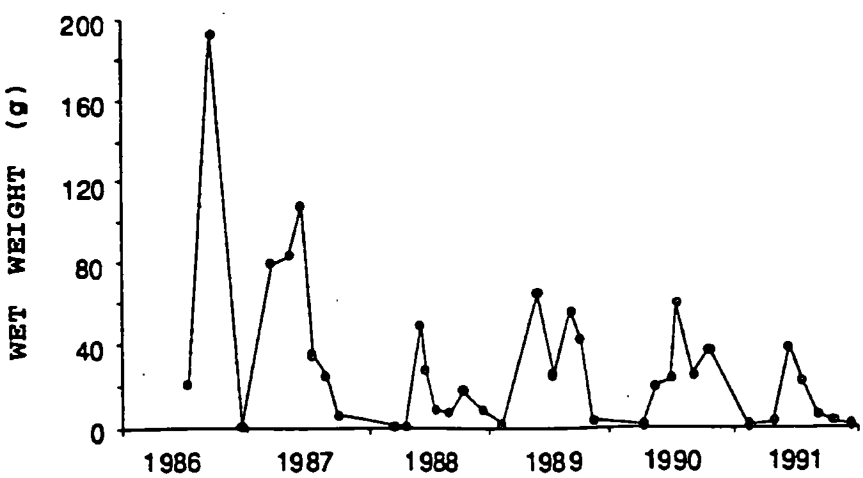


Fig. 22. Mean wet weight of wrasses caught in beach seine in Masfjorden.

The mean weight of wrasses changed suspiciously over time; it showed a definite decline during the period (Fig. 22). This especially applies to goldsinny-wrasse, which was the most numerous of the wrasses in net hauls, but it can also be seen for ballan wrasse. The development may be related to increased predation pressure, which over time resulted in the disappearance of large individuals and also that fewer individuals reach a large size (mean weight declines), although the numbers also vary dependent on the reproductive success each year. The wrasses live several years and may therefore be more subject to heavy predation than the two-spotted goby.

6.7 MODELING THE CARRYING CAPACITY IN MASFJORDEN

One of the goals of ecological modeling is to determine the characteristics of good release areas for cod. This implies that one has to identify and quantify processes that are important for the production potential of cod. We have attempted to make the models fairly general so that they can be applied to other areas than Masfjorden.

6.7.1 MODEL FOR 0-GROUP COD

GISKE *et al.* (1991) developed a model for the pelagic ecosystem in Masfjorden, and this model is linked to the cod through its prey. Nutrients, phytoplankton, zooplankton, gobiids, and cod are the most important state variables in the model. Production is driven by irradiance, temperature, freshwater run-off, upwelling and water exchange across the sill in the fjord. The results show that advection is one of the main driving forces in the system (advection = transport of plankton by water currents). The importance of variations in advection is illustrated in Table 14.

Table 14. Model simulations showing the production of gobiids and cod as a function of current velocity across the sill. The current velocity is a measure of how much zooplankton that is advected into the fjord.

Current across sill (cm/s)	Production of gobiids (tonnes wet weight)	Production of cod (tonnes wet weight)
0	-6.0	-0.1
5	6.8	0.4
10	17.5	0.8
15	26.4	1.1
20	34.8	1.4

The exchange of water near shore is linked to the water transport across the sill. When the current across the sill increases from 0 to 20 $m \cdot s^{-1}$, the production of gobiids increases 40 fold and the production of cod 15 fold. Small fish that prey on plankton in the littoral zone are among the species that are most dependent upon transported plankton, although other organisms are directly or indirectly dependent upon advection. For instance, large cod eat wrasses that eat blue mussels that eat phytoplankton. However, not just food availability determines how much plankton eating fish the littoral zone can produce. The habitat will also have a saturation point for how many individuals of a species it can contain. We do not know what the saturation level (maximum number of individuals$\cdot m^{-2}$) is for gobiids or cod in Masfjorden.

6.7.2 MODEL FOR 0,1,2 AND 3+ GROUP COD

Fig. 23 shows how the pelagic processes are linked to the trophic interactions in the littoral zone. The model includes 0, 1, 2 and 3+ group cod, as well as the main prey of these age-groups (Table 15). Competition and cannibalism is added by specifying the prey/predator relationships. The groups "gobiids" represent all zooplankton eating fish in the littoral zone and "wrasses" include fish that only prey on the benthic fauna. The competitors of cod are not specified as a single group, but are included in the group "cod". Competition for gobiids as prey items is incorporated for all groups of cod, and competition for bottom fauna as prey is between all groups of cod and wrasses. There also is competition for wrasses as prey between 1-group cod and older cod, and competition for 0- and 1-group cod as prey between 2-group cod and older ones. Gobiids compete for zooplankton as prey with pearlsides, medusas and benthos.

In the model, the fjord is divided into three sections: 1) pelagic area, 2) littoral area and the water column down to 3 m depth, and 3) the benthic habitat down to 20 m depth. 0-group cod and gobiids are found in shallow-water in habitat 2, whereas the older cod, the wrasses, and the benthic fauna also are found deeper. With the exception of benthic fauna, the start values of the state variables in the model are chosen as the mean of estimated biomasses in Masfjorden over 3-4 years. We lack quantitative estimates of the benthic fauna in Masfjorden, and have used mean values for the shallow areas of the North Sea. Details on initial values for the state variables and parameters are described in GISKE *et al.* (1991) and in SALVANES *et al.* (1992).

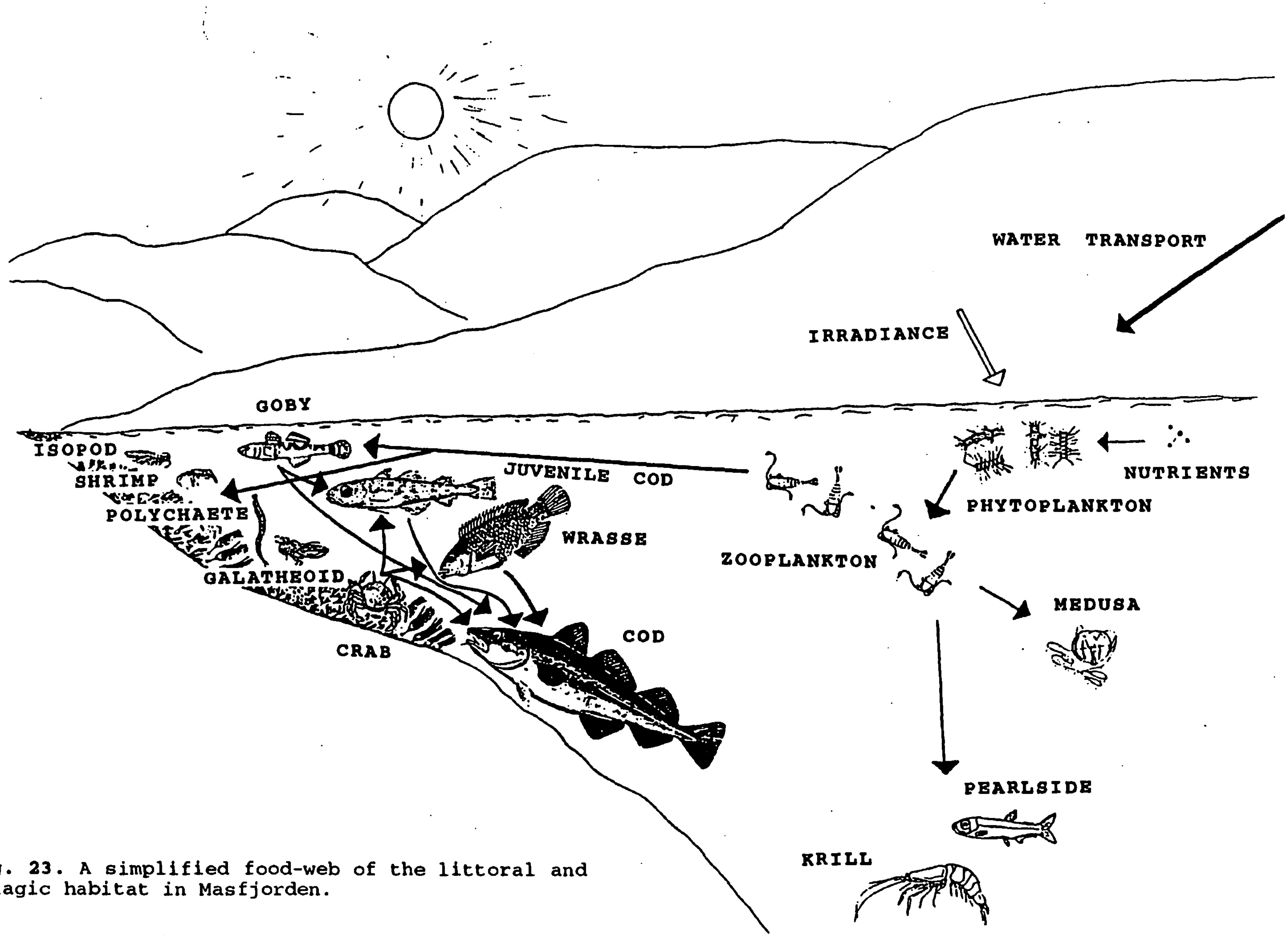


Fig. 23. A simplified food-web of the littoral and pelagic habitat in Masfjorden.

Table 15. Predator-prey relationships specified in the Masfjord model.

Predatorer	Prey: Phyto-plankton	Zoo-plankton	Benthic fauna	Gobiids	Wrasses	0-group cod	1-group cod
3+group cod			x	x	x	x	x
2-group cod			x	x	x	x	x
1-group cod			x	x	x		
0-group cod			x	x			
Wrasses			x				
Gobiids		x					
Pearlsides		x					
Medusas		x					
Zooplankton	x						
Benthic fauna		x					

Simulated production in an average year

Annual production in an average year was 2,341 tonnes carbon (Table 16). This equals a net production of 90 g $C \cdot m^{-2} \cdot yr^{-1}$, which is normal in coastal waters (MATTHEWS and HEIMDAL 1980). Total annual net production of cod, wrasses and gobiids was 56.3 tonnes wet weight. This equals a fish production of 2.5 g $C \cdot m^{-2} \cdot yr^{-1}$. Estimates for the North Sea is 1.7-1.8 g $C \cdot m^{-2} \cdot yr^{-1}$ (0-groups fish not included). On Georges Bank, a productive area, the production was estimated as 4.5 g $C \cdot m^{-2} \cdot yr^{-1}$.

Table 16. Accumulated net production simulated for an average year. The simulations were performed with the improved model and the ratio between produced gobiids and 0-group cod differ from that presented in Table 14.

State variables	Annual net production	
Phytoplankton	2340.9	tonnes carbon
Herbivore zooplankton	328.9	"
Medusas	-7.5	"
Pearlsides	14.6	"
Gobiids	14.7	tonnes wet weight
Bottom Fauna	46.0	"
Wrasses	3.2	"
0-group cod	21.9	"
1-group cod	7.8	"
2-group cod	6.6	"
3+group cod	2.1	"

The production of cod (38.4 tonnes in an average year) also includes the competitors of cod (pollock, saithe and poor-cod). The difference between simulated cod production and an independent empirical estimate of this will indicate the level of biomass contributed by competitors in the estimate. An empirical estimate for production of cod can be obtained as follows: turnover rate (production/biomass) for exploited fish populations is approximately equal to the total instantaneous mortality rate (PITCHER and HART 1982). For cod in Masfjorden, SALVANES and ULLTANG (1992) have estimated Z to be 1.0 per year, and the total biomass to about 28 tonnes. When Z=1.0 the empirical estimate of cod production is then 28 tonnes. The difference between empirical and simulated production becomes 10.4 tonnes (translator's comment: problems with the logic in the original document). This difference represents the production of competitors. In Masfjorden, the biomass of the cod's competitors were estimated as 33 tonnes (SALVANES *et al.* 1992). Since the empirical values are well above the simulated ones, one can certainly not conclude from the model estimates that there are under-utilized food resources for released cod in an average year.

Production potential for cod in years that differ from the average

Years that differ for the average are identified based on deviations in water exchange across the sill, deviations in benthic fauna, and deviations in recruitment. If two or three of these factors are changed in the same direction, they will accentuate the deviation in simulated production (Table 17). If all three factors are 100 % higher than in an average year, the net production will increase 2.6 times. Dividing the factors by two would reduce the net production to one third of that in an average year.

Table 17. Relative importance of recruitment, advection and biomass of benthic fauna for the production of cod. The numbers refer to net yearly production as a fraction of the production in an average year.

Category	0.5 x mean	2.0 x mean
Bottom fauna	0.68	1.50
Advection	0.81	1.33
Recruitment	0.76	1.29
Bottom fauna + advection	0.42	1.80
Bottom fauna + recruitment	0.45	2.05
Advection + recruitment	0.64	1.72
Bottom fauna + advection + recruitment	0.33	2.63

The potential for cod production in Masfjorden

Potential production was investigated by first simulating the production in a so-called basic run. Basic run represents an average year regarding the amount of plankton and other organisms in the fjord. By changing the values of the state variables one can then investigate whether the potential is greater in an average year within certain limits. In an average year there are about 184,000 of 0-group cod by August 1. We investigated how changes in recruitment mass influences the production given two different rates of advection (0.5 and 2 times basic run) and for one level of benthic biomass (0.5 times basic run) (Fig. 24). The results show that if water exchange and biomass of benthic fauna are average, then the maximum potential production capacity of cod seems to be 58 tonnes. If the rate of water renewal is doubled then the production potential for cod will be about 73 tonnes. A reduction in the rate of water exchange results in lower production. Reducing the benthic biomass by a factor of two will, by itself, reduce maximum cod production to about 35 tonnes.

Generally, the model does not predict positive effects of releases. The results show that releases probably are most appropriate during years when the food availability is higher than normal. Therefore it will be important to find a method which can determine the production potential early enough so that one can determine whether stocking of juvenile cod should occur or not. The problem is that one cannot determine the potential based on local conditions only, since the potential also is dependent upon weather conditions (current generating processes) which are stochastic in principle.

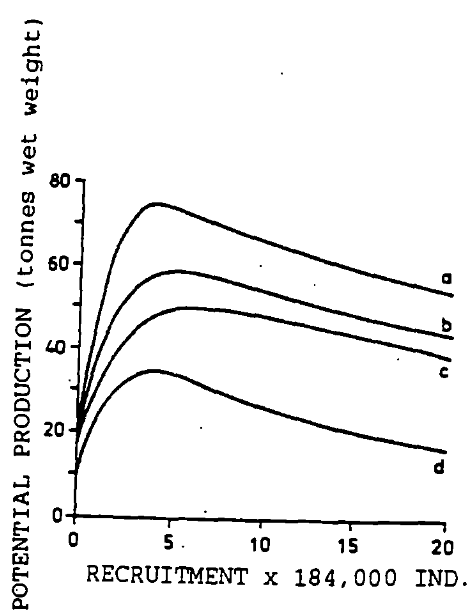


Fig. 24. Simulated production curves for the entire cod population as a function of changes in recruitment. a) advection rate is twice as in basic run (average year); b) advection rate and benthic biomass as in basic run; c) advection rate half of that in basic run; and d) the initial benthic biomass is half of that in the basic run.

6.8 MODEL FOR RELEASE STRATEGY AND MANAGEMENT

An overview of the model is present in FOSSÅ and NORDEIDE (1991). The following main points were important in the analysis:

1. Release strategy, i.e., simulate the reward of releasing cod every year, every second year, or every third year. This analysis includes the importance of cannibalism for yield.

2. Fishing mortality, importance for releases.

3. Importance of reduction of predators (especially pollock) in the system for yield.

The parameters used in the model are obtained from the results of releases in Masfjorden and Heimarkspollen in Austevoll (Table 18). The model is scaled to the size of fish populations in Masfjorden.

Table 18. Parameter values for the driving processes. D = predation mortality on 0- and 1-group cod. A = number of predators. M and F are annual instantaneous natural mortality and fishing mortality, respectively.

Process	Parameter value	Source
Predation on 0-gr.	D=0.9 x A	Fitted to value observed in nature
Predation on 1-gr.	D=0.35 x A	Fitted to value observed in nature
Predation on 2-gr.	M=0.2	Used by ICES
Predation on 3-gr.	M=0.2	Used b ICES
Fishing mortality 1-gr.	F=0.1	Svåsand pers. comm.
Fishing mortality 2-gr.	F=0.6	Svåsand pers. comm.
Fishing mortality 3-gr.	F=0.6	Svåsand pers. medd.

6.8.1. SIMULATIONS

Table 19 and 20 show results of different simulation cases. In Table 19, the number of individuals are listed, whereas in Table 20 numbers are listed as percentage of released juveniles. The results show that there is no great difference in percent yield whether one releases fish every year, or every second or third year. A complete moratorium on the fishing of small cod results in an increase of about 60 % when cod are released every year, and about 130 % when releases occur every third year. The reward therefore become largest by adopting release strategy no. 3. The single step that gives the largest percentage yield, is to make the number other predators half as large. This causes a 160 % increase in yield when fish are released every three years. Again we can see that the effect of this step is greatest when cod are released every third year. A combination of fishing moratorium and predator reduction results in the largest yield.

Table 19. Results of simulations after 80 months with three different release strategies. F = fishing, A = other predators than cod.

Release regime	Number of releases that have grown to age-3	Yield	Number fished	Yield tonnes	Yield if F=0	Yield if A=one half (5,000)	Yield if F=0 A=one half (5,000)
Every year	400 000	11 969	58 304	11.97	19 654	27 289	59 558
Every 2nd year	200 000	6 205	34 687	6.21	10 058	14 536	29 300
Every 3d year	200 000	8 615	32 903	8.62	20 000	21 967	49 229

Table 20. Percentage yield for released fish after 80 months. Three different release strategies were tested. F = fishing, A = other predators than cod.

Release regime	Number of releases that have grown to age-3	Yield	Number fished	Yield if F=0	Yield if A=one half (5,000)	Yield if F=0 A=one half (5,000)
Every year	400 000	3	14.6	4.9	6.8	14.9
Every 2nd year	200 000	3.1	17.3	5.0	7.3	14.7
Every 3d year	200 000	4.3	16.7	10.0	11.0	24.6

6.8.2 CONCLUSIONS

When the model is run on the present initial values (fishing mortality included, 10,000 other predators, and 5,000 age-3 cod) there were no large differences in the percentage yield of releases by adopting any of the three release regimes. Releases done every third year, however, resulted in the highest yield per released fish. This difference increased if fishing mortality and amount of predators in the system were removed. This indicates that it is most sensible not to release juveniles until the previous release group has grown to optimum size and has been harvested.

The results show that by reducing the fishing mortality on small fish, coupled with reduction of the number of predators in the system, one can achieve a substantial increase in yield. By reducing the fishing mortality of small cod, the yield can possibly become larger than what is determined here. Results from Austevoll show that the present fishery is very size dependent, and that individual growth is larger than the observed population growth (SVÅSAND pers. comm.). If the fish grow fast and have a moderate mortality, it will be more advantageous to further postpone the fishery than if the fish grow slowly at similar mortality.

The conclusion is therefore that it is advantageous to manage the fishery and releases in a manner that reduces fishing mortality and the amount of predators in the system, when combined with a suitable release strategy.

7. CONTROLLING ECOLOGICAL FACTORS

Zooplankton is either directly or indirectly food for the cod's prey (zooplankton - gobiids - cod; zooplankton - bottom fauna - cod; zooplankton - bottom fauna - wrasses - cod). Since the availability of zooplankton to a large extent is determined by the water renewal across the sill, which in turn is controlled by wind-driven changes in the coastal current which transplants through Fensfjorden to Masfjorden (AKSNES *et al.* 1989), this may indicate that the local production is controlled indirectly by regional meteorological conditions. Large net influx of zooplankton is expected when southerly winds dominate, whereas large export is expected when northwesterly winds have dominated. This implies that release of the same number of juveniles may result in different production because of different amounts of zooplankton being present during the release years.

The extent of the littoral vegetation is critical for the quality of the rearing habitats for 0-group cod in fjord areas of western Norway. This is determined by bottom slopes; steeper rock inclines results in less area covered by kelp. In addition, the extent of the kelp beds is reduced towards the inner part of the fjord, and kelp may be completely absent in the innermost areas. Mass releases of cod or other fishes in areas where the fish can not find relief habitats, will only benefit pollock and other predators. The vegetation enhances survival of the cod, although food availability is critical for survival, and also determines how fast the cod will grow to fishable size. We have estimated that if the small cod were to base their growth on the food produced in the kelp beds where they live, about 1,000 of 0-group cod could be sustained in Masfjorden. A normal year-class strength in the fjord, however, is about 10-100 times lager, and this shows the importance of transported (advection) food in relation to the locally produced food. The gobiids, which cod eat, base their growth on zooplankton being transported into the kelp beds from the outside. The model for cod production in Masfjorden have shown that one of the most important factors for the carrying capacity of 0-group cod is the water exchange between the kelp zone and the open water masses outside. This rate then depend on the exchange between the fjord and the coastal water. Concerning growth conditions, we expect a decreasing gradient from islands and open coastal areas towards the head of the fjords. This has also been determined by DANNEVIG (1954).

The production model for cod in Masfjorden is fairly general, Even if the state variables and parameters are from Masfjorden, the model can be applied to other areas. We therefore would like to point out some general implications based on our results: 1) the carrying capacity for 0-group cod seems to be determined by density dependent competition and cannibalism between groups within the ecosystem; 2) the same amounts of juveniles released during different years are expected to yield different production dependent upon net annual influx of zooplankton; 3) different areas are expected to show different production potentials dependent upon area topography. Differences in topography may be expressed as the incline of the literal zone, which then results in different habitat sizes in different areas. The difference in sill area/fjord volume and fjord volume/length of coastline within the release area, will influence the water exchange and thus the availability of zooplankton, which subsequently has been found to regulate the production potential of cod.

Whether sea ranching of cod will become economical, will depend on growth and survival of the released juveniles, among other factors. These two key factors subsequently depend upon a variety of biological factors, such as food availability, size of juveniles at the time of release, the amount of predators and the extent of cannibalism. Fishing mortality (for instance sport fishing and trap fishery on small cod) may also be substantial.

The best situation for the cod is for it to be in a habitat where the food availability is good, with not too many competitors, and with as few predators as possible. These factors can in principle be manipulated by choosing different release strategies. If we release cod year after year at the same sites, a predator population will be built up and thus much of the juveniles in the subsequent release will fall prey to the cod that were released earlier. Additionally, most prey species will be subject to a high and constant predation pressure, which may prove harmful over some time. A release strategy which may mitigate the problem with cannibalism and predation pressure, is to release cod in one area and then not release more fish there until the first release has been harvested. In this manner the population of predators are reduced prior to new releases. Also, the cod will switch to new prey groups as it grows, and the prey population in an areas will therefore experience some relief from predation pressure.

It may be desirable to release juveniles at different sites in subsequent years, a strategy which will resemble alternating farming. Some of the background for the desire to construct the model in Chapter 6.8 was the notion of conducting alternating sea farming of cod. The simulation results showed that there was little difference in percentage yield from releases whether cod were released every year or every second or third year at the same site. Releases every third year, however, gave the highest yield per released fish. This difference increased if one had no fishing mortality and reduced the amount of predators in the system. This should indicate that it is most sensible to not release juveniles until the fish from the last release have grown to optimal size and are harvested.

The results also showed that reduced fishing mortality on small fish in combination with reduced number or predators in the system would result in increased yield. By reducing the fishing mortality on small cod the yield can probably be greater than what is estimated here. Results from Austevoll showed that the fishery is very size dependent, and that the individual growth is faster than the observed population growth (SVÅSAND pers. comm.). When fish grow fast and have moderate mortality it will be advantageous to postpone the fishery for a longer time than if the fish had slower growth rate and the same mortality pattern.

8. EFFECTS OF RELEASES ON THE ECOSYSTEM

8.1 THE EFFECT ON WILD COD, POOR-COD AND POLLOCK

Wild cod, poor-cod and pollock are the most important predators and competitors to released cod. Their population trends, condition factors and liver indices were therefore monitored before and after releases. The mass release in Masfjorden in August 1988 resulted in significantly larger catches, per unit of effort, of juvenile cod of the 1988 year-class in Masfjorden as compared to the control areas outside Masfjorden. This applies to the releases done prior to and including the age of 4th quarter, or including the 1st quarter of 1989. Similarly, mass releases in September 1989 resulted in increased catches per unit of effort until an age of 5 quarters, or including the 2nd quarter of 1990. Potential effects of releases on wild cod and other species are therefore expected to be largest from August 3^{d} quarter of 1988 including 1st quarter of 1989, and from 4th quarter of 1989 including 2nd quarter of 1990.

The mass releases have probably resulted in somewhat reduced growth, condition factor and liver index of cod, pollock and poor-cod. This effect, however, is weak and in most cases not significant. When compared to the large natural variations from period to period, the effects of releases must be described as minor. Released cod were to a large extent subject to predation, and after 1/2 to 3/4 year after being released, the density of cod in Masfjorden was similar to that of the control area. Better survival of released cod and longer periods of density differences between areas, would probably have resulted in larger differences in cod, pollock and poor-cod between Masfjorden and the control area.

8.2 THE EFFECT ON PREY

To determine potential effects from releases on the food base, some of the important prey, which could be quantified, were monitored after releases. Initially one might expect that some of the cod's prey may be subject to harmful effects if the predation pressure is increased in subsequent years by releasing cod. Based on the population development of two-spotted gobies during the years 1986-91, we can not see that the releases have had any effects on their numbers. In Masfjorden, the longevity of two-spotted goby is 1.5 years and the population is severely decimated each year. However, the species appears to have a large enough reproductive potential to bounce back each year and can respond with high reproductive success if the environmental conditions become favorable. This may indicate that the species has enough escape habitats so that they are not preyed to extinction. The releases therefore do not seem to be harmful for the populations in the fjord.

Wrasses are also food for large cod. These fish vary in numbers in concordance with the two-spotted goby. The mean weight of wrasses changed suspiciously over time in that it showed a definite decline during the period. This especially applies to goldsinny-wrasse, which was the smallest and most numerous of the wrasses. This development may be related to increased predation pressure, which over time resulted in the disappearance of large individuals (the mean weight declined), although the numbers vary dependent upon the reproductive success each year. The wrasses live several years and may therefore be more subject to heavy predation than the two-spotted goby.

9. CAN PRODUCTION OF COD IN MASFJORDEN BE ENHANCED BY RELEASES?

The goal of the Masfjord project was, among other things, to determine which factors that regulate the cod production in a fjord, and to determine whether Masfjorden has available resources that could support sea ranching. Here we will elucidate Masfjorden's potential.

The recruitment and year-class strength of some marine fishes are very variable (BERGSTAD *et al.* 1987). The literature concerning this topic is substantial and contains numerous hypotheses (ANDERSON 1988). Most authors, however, agree that year-class strengths are determined relatively early in the life cycle. For codfishes, this occurs about 3-5 months after hatching. The release experiments were based on this information. The idea was that cod should be hatched and then fed under controlled conditions with a surplus of feed and few predators. In this manner a large amount of small cod could be helped to pass thorough the critical period of high mortality. The cod were then to be released in the sea where the natural mortality were reduced, and the year-class strength would to then to a large extent be predetermined. These cod would then grow up and recruit to the commercial fishery as an addition to the wild cod. In this way we hoped to enhance the local populations.

In Masfjorden, we increased the number of cod during the first quarters after release (as compared to the control area). However, the mortality was higher in the release area than in the control area, This certainly applied to the 1-group stage, and probably also to the 0-group stage. When the cod became two years old and recruited into the commercial fishery in the fjord, the density of cod in the release area was not measurably different from the control area. Release of 0-group cod in 1988-1990 has thus not increased catches of 2-group cod in Masfjorden. The factors determining the strength of a year-class are, at the 1-group stage, still forceful enough to reduce a strong year-class to a weak year-class.

Causes of mortality after mass releases may be many. Small individuals of a species generally have more enemies and this greater mortality than large individuals, assuming other factors are equal. The results from Masfjorden show that cod released at a larger size had the highest recapture percentage. Food availability is one of the most important growth factors, and we released cod in years when the food availability was different. Cod released during a period of good food availability grew the fastest and had the highest percentage recapture. Food availability therefore seems to be one factor that determine whether releases of cod will result in increased production.

We have also estimated how many small cod that could subsist on the production of two-spotted goby. The conclusion was that gobiids did not represent a resource that could have been a potential food source for an enhanced production of cod during the years studied. In this evaluation it was also included that cod eat other food and that cod comprise 5-15 % as numbers and 45-50 % as biomass relative to their competitors in Masfjorden. KAARTVEDT et al. (1988) also arrived at the same conclusion based on a calculation which incorporated krill and shrimp as potential food sources in the fjord. We have also done dynamic simulations of the carrying capacity, with pelagic organisms included as part of the food source. These simulations estimated a potential doubling of the cod production if cod also utilized the pelagic resources. However, it must be noted that the cod are not known to prey on these organisms, even when growth and survival appear to be poor because food is scarce.

How then do these estimations agree with our experiences based on the releases? The results from some small releases show that for every released fish, we harvested between 10 and 60 g wet weight (see Table 3). Estimated as number of kg in return for each kg released, the values vary from 0.19 and 0.83. This implies that we got less in return than was initially released. Percentage recaptured from the mass releases are not yet estimated, but we predict it to be poorer than for the small releases, because the released fish were smaller. We have shown a positive correlation between size at time of release and percent recapture. However, we can not just use the percentage recaptures to judge the success of releases since it may depend upon the fishing effort. But the development of the cod populations, revealing high mortality of both wild and released cod, supports this conclusion (see Figure 7).

The answer to the question in the chapter heading therefore appear to be clear as far as Masfjorden is concerned: we have not enhance the cod production to any extent in Masfjorden by releasing juveniles. The recaptures are so low that there is no point of calculating the economics in this.

For comparison we can look at the results of releases of 0-and 1-group cod in Austevoll, in a project directed by Terje Svåsand. In the years 1983-87 there were released 40,370 juveniles. Of these 19.4 % were recaptured (number corrected by a factor of 1.23 for 10 % tag loss and 90 % reporting of recaptures [SVÅSAND and KRISTIANSEN 1990a]). The mean weight of the recaptures was 0.733 kg and yield per released cod was 0.142 kg (SVÅSAND pers. comm.). Even if this resulted in a biological surplus, SANDBERG (1988) calculated that sea ranching based on such recaptures and existing fishing pattern is not economical.

In Austevoll, the percentage recaptured was higher than in Masfjorden and this applies to both Heikmarkspollen and the areas outside. The growth of cod in Heikmarkspollen were similar to that of Masfjorden, whereas the growth in the area outside the poll was significantly higher (KRISTIANSEN 1987). Thus, it is necessary to determine what ecological conditions in the different habitats that caused this. It is also possible that topographical features of the habitats were important for the recapture percentage, since it may not be equally feasible to catch fish in the different habitats. This may be one of the reasons for the lower percentage recaptured in the control area outside Masfjorden than within the fjord itself. Øygarden is known as an open habitat which also has lower recapture percentage than Masfjorden. The next step is to discuss whether it is possible to find more suitable habitats along the coast than the habitats already investigated in Austevoll and Masfjorden.

In Masfjorden it seems that the potential for economical sea ranching of cod is just not present, probably because the carrying capacity is too low. However, we have collected much information on which factors that determine good habitats for cod in western Norway and how one ought to release juvenile cod. We sum up our experiences as follows:

1. Where to release cod:
   a. in locations where there is good exchange of water and therefore rich influx of zooplankton. If these areas also are know to have seasonal migrations of sprat and herring this will be very advantageous in years when these species are abundant.
   b. in locations with large shallow-water areas.

2. How to release and manage the cod:
   a. it seems to be safest to change release locations so that cod are not released in the same locations each year.
   b. one absolutely has to change the fishing pattern from that of the present. Fish smaller than the desirable size should not be caught.
   c. the technical aspects of the method function very well.

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