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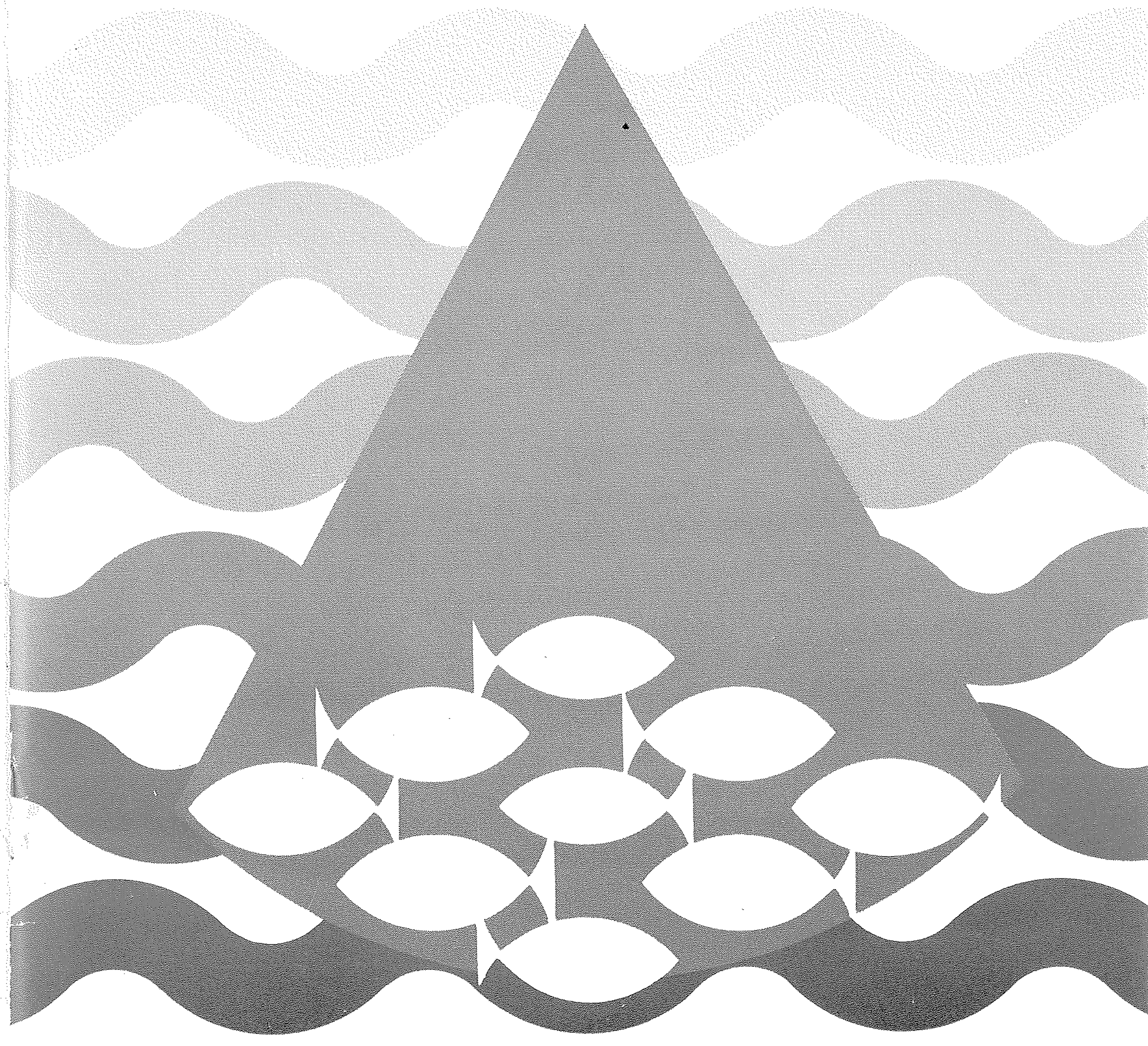

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INDIVIDUAL GROWTH RATE AND AGE AT SEXUAL MATURITY IN RAINBOW TROUT

By
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ABSTRACT

NÆVDAL, G., HOLM, M., LERØY, R. and MØLLER, D. 1979. Individual growth rate and age at sexual maturity in rainbow trout. *FiskDir. Skr. Ser. HavUnders., 17*: 1–10.

Growth rate possible connection between growth rate and age at sexual maturity were studied on individually tagged rainbow trout from different sib groups. Considerable variation in growth rate and age at first sexual maturity was found among sib groups. Significant correlations were found between size (length) of the individual fish and group mean, measured at different times during the sea phase. The mean lengths within groups of fish maturing during their third year were significantly higher than for fish still immature in the autumn preceding spawning, as well as half a year before and even one year before spawning.

The relationship between sex and size of the fish was not clear, but in some groups the males were on average larger than the females. Fish maturing during their second year (mostly males) showed nearly the same mean size as immature fish of the same age before the spawing season. They grew considerably less during the spawing season, and showed somewhat increased mortality rate, but during the next summer they matured again and showed greater relative growth rate than the other fish.

INTRODUCTION

Tentative results from experiments with selective breeding of rainbow trout, *Salmo gairdneri,* were described in two previous reports (NÆVDAL *et. al.* 1975, MØLLER *et al.* 1976). The first year class of these experiments hatched in 1972. Since then, new material has been collected each year, and gradually more study has been carried out on selected fish from the first two year classes.

The first year classes were used to study the variability in traits of economical importance for fish farming, especially growth rate and age at first sexual maturity. The influence of genetic factors on these traits was estimates from full sib and half sib correlations.

Some of the fish from the first and second year classes were individually tagged. In the present report the data of the individually tagged fish are used to study correlations between growth rates at different ages and the possible connection between growth rate and age at first sexual maturity.

MATERIALS AND METHODS

Egg and milt material for the experiments were obtained from a commercial Norwegian fish farm in the winter of 1972 and 1973. In 1973 milt from three males from another fish farm was also included.

The experiments were based on sib groups. Normally the egg portion of each female was divided into two equal parts and fertilized with milt from two different males. Each male was normally used for two females. This 2 x 2 pattern of combinations was only partly followed in 1973.

The eggs were hatched in the hatchery at the field research station in Matredal (Akvakulturstasjonen Matre). From start of feeding to an age of 16 months (1972 year class) or 8 months (1973 year class), the fish were kept in 1.7 m^3 cylindrical tanks. Afterwards they were kept in floating cages in brackish water near the station until they were transferred to full strength sea water. The 1972 year class was sent to a shore enclosure at the fish farm Eros Laks, Bjordal, when aged about 18 months, and the 1973 year class to floating cages at another fish farm, Risnesfisk, Brekke, when the fish were about 14 months old.

During their first year, each group was kept in a separate tank. At the age of about six months they were marked with combinations of fin clipping (adipose fin or pelvic fins). In November 1973 about 100 fish of each of eight sib groups of the 1972 year class were individually tagged with different types of Floy Tags (FT 4 Spagetti Tag, FT 4 Lock-on, FT 6 Dart Tag and FD 67C, all from Floy Tag and Mfg., Inc. 4616 Union Bay, Pl. N.E. Seattle, Washington 98105, USA). In April 1975, 125 fish from each sib group of the 1973 year class were tagged with FT 4 Lock-on tags.

Due to fouling with mussels and algae, tag losses were heavy after about 6 months, especially the FT 6 Dart Tag gave few data. The results of the tagging experiments and comparisons of the different types of tag are dealt with in a separate report (NÆVDAL, HOLM and KNUTSSON 1977).

The lengths of 100–200 fish of each sib group were recorded in spring and autumn each year. Individual weights were recorded at slaughtering for the 1972 year class and at 24 and 30 months for the 1973 year class. Stage of maturity was recorded in the autumn and spring of the second year, and in the autumn of the third year. Aged 30 months, most of the fish were slaughtered, while 20–30 individuals of each group were kept alive for producing the F_2-generation.

In the present report, mainly data for the individually tagged fish are dealt with. Standard methods were used for calculating means, correlation coefficients etc. and also for variance analysis.

RESULTS

GROWTH RATE AT DIFFERENT AGES

Marked differences between sib groups in mean growth rate and age at first sexual maturity were observed. These differences were dealt with in previous reports (NÆVDAL *et al.* 1975, MØLLER *et al.* 1976). Tentative estimates of heritability factors also gave rather high values.

To compare the growth rate at different ages, correlation and regression factors between mean length for each group at the different measurements were calculated. The results are presented in Tables 1 and 2. Fish maturing during their second year were not used in these calculations because maturation greatly affects the growth rate.

Correlations were high for observations taken within 6 or 12 months, but rather low for those taken at broader time intervals, especially in the 1973 year class.

To analyse correlation between individual sizes at different ages, the size of the individually tagged fish at the different measurements was compared (Table 3). The coefficients were in the same order of magnitude for individuals as for the sib groups means, and for the time interwals up to 12 months the correlations were rather high.

Table 1. Correlation coefficients (above diagonal) and coefficients of regression (below diagonal) of mean length of rainbow trout hatched in 1972 and measured at five different ages.

Age (months)	6	12	18	24	30
6	—	0.81	0.67	0.48	0.06
12	1.47	—	0.40	0.25	−0.18
18	1.60	0.55	—	0.79	0.63
24	0.47	0.22	0.50	—	0.74
30	0.16	−0.26	0.61	1.14	—

Table 2. Correlation coefficients (above diagonal) and coefficient of regression (below diagonal) of mean length of rainbow trout hatched in 1973 and measured at five different ages.

Age (months)	6	12	18	24	30
6	—	0.90	0.64	0.73	0.49
12	1.22	—	0.65	0.73	0.59
18	0.66	0.51	—	0.95	0.83
24	0.75	0.64	1.26	—	0.92
30	0.67	0.61	1.10	0.86	—

Table 3. Correlation coefficients (above diagonal) and coefficient of regression (below diagonal) of lengths and waights of rainbow trout at different ages.

Year class and age	1972			1973			
	length			length		weight	
	18	26	30	24	30	24	30
1972 length 18	—	0.67	0.58	—	—	—	—
» 26	0.77	—	0.86	—	—	—	—
» 30	0.81	1.01	—	—	—	—	—
1973 length 24	—	—	—	—	0.87	—	—
» 30	—	—	—	1.02	—	—	—
1973 weight 24	—	—	—	—	—	—	0.82
»	—	—	—	—	—	1.56	—

RELATIONSHIP BETWEEN AGE AT FIRST SEXUAL MATURITY AND GROWTH RATE

The fish of each year class were separated according to sib group, sex and age of maturation (maturing in their third year or later), and lengths and weights were subjected to an analysis of variance to see if any of these factors influenced the size at one and a half, two, and two and a half years of age. Early maturing fish (i.e. mostly males, maturing during their second year of life) were omitted from the present analysis because they were rather few in most groups, and because most fish were tagged after the maturation of these males. They are, however, dealt with in a later chapter (p. 8, Table 12).

The results for the 1972 year class are shown in Tables 4–7.

Tables 4 and 5 show that whether the fish are maturing or not influences the size in the autumn when the fish are two and a half years old. Maturing fish of both sexes have a somewhat greater mean size than fish that are still immature, and the variations between sib groups are also evident from the original data. No effect of sex could be seen, even when eliminating the variation caused by the two other sources.

Likewise, Tables 6 and 7 show that the effect of group and of age at maturation may be seen both in the spring half a year before maturation and in the autumn one year before maturation. The effect of sib groups has been found to be clear at all ages (MØLLER *et al.* 1976), and from the present data it is evident that the late maturing fish, that is those maturing at an age of three and a half years or older, show a lower mean growth rate than their early maturing sibs.

Table 4. Analysis of length variance in rainbow trout two and a half year's old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	150.50	p >0.2
Within sex	223		
Between age of maturation	2	229.65	0.001<p<0.01
Within age of maturation	231		
Between sib groups	28	40.8	p<0.001
Within sib groups	203	19.03	
Total	234		

Table 5. Analysis of weight variance in rainbow trout two and a half years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	15.15	p>0.2
Within sex	233		
Between age of maturation	2	6.77	0.001<p<0.01
Within age of maturation	231		
Between sib groups	28	1.00	p<0.001
Within sib groups	203	0.31	
Total	234		

table 6. Analysis of length variance in rainbow trout two years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	53.56	p>0.2
Within sex	206		
Between age of maturation	2	96.50	p∼0.05
Within age of maturation	204		
Between sib groups	28	30.51	p<0.001
Within sib groups	176	4.72	
Total	207		

Table 7. Analysis of length variace in rainbow trout one and a half years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	4.74	p>0.2
Within sex	166		
Between age of maturation	2	260.27	p<0.001
Within age of maturation	164		
Between sib groups	27	17.34	0.01<p<0.05
Within sib groups	137	8.59	
Total	167		

Table 8. Analysis of length variance in rainbow trout two and a half years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	210.04	p>0.2
Within sex	1288		
Between age of maturation	2	1 662.20	p<0.001
Within age of maturation	1 286		
Between sib groups	58	75.86	p<0.001
Within sib groups	1228	14.80	
Total	1289		

Table 9. Analysis of weight variance in rainbow trout two and a half years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	15683.02	p>0.2
Within sex	1288		
Between age of maturation	2	378485.64	p<0.001
Within age of maturation	1286		
Between sib groups	58	9138.26	p<0.001
Within sib groups	1228	1297.31	
Total	1289		

Table 10. Analysis of length variance in rainbow trout two years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	∼ 0	p>0.2
Within sex	1285		
Between age of maturation	2	898.0	p <0.001
Within age og maturation	1283		
Between sib groups	58	76.14	p<0.001
Within sib groups	1225	5.13	
Total	1286		

Table 11. Analysis of weight variance in rainbow trout two years old.

Source of variation	d.f.	Mean squares	probability
Between sex	1	53408.59	p>0.2
Within sex	1284		
Between age of maturation	2	5150068.05	p<0.001
Within age of maturation	1282		
Between sib groups	58	414705.33	p<0.001
Within sib groups	1222	34518.65	
Total	1285		

Corresponding results of the 1973 year class are shown in Tables 8–11. A significant effect both of sib groups and age of maturation could be seen on lengths and weights at slaughtering when the fish were 2½ years old (Tables 8 and 9), and these effects were also evident the preseeding spring (Tables 10 and 11). Also in this year class, late maturing fish showed a lower mean growth rate than their earlier maturing sibs.

Effect of sex could not be seen when analysing the material this way, but when eliminating the effect of sib groups and age of maturation, a significant effect of sex was found. In the total material the mean sizes of the males were a little greater than those of females, but this sexual dimorphism was more evident within some groups than in others.

GROWTH RATE AND SURVIVAL OF THE EARLIEST MATURING FISH

NÆVDAL *et al.* 1975 and MØLLER *et al.* 1976 mentioned that very clear differences between sib groups were found in relation to proportions of fish maturing in their second year (nearly exclusively males). The individual taggings were made when the first maturing fish were already near to spawning (1972 year class) or spent (1973 year class). These early maturing fish were eliminated from the material when making the analysis of correlations and variance. However, especially in the 1973 year class, the growth and survival of these early maturing males could be observed from November 1974, when they could be classified as maturing, until slaughtering one year later. Of the 1972 year class only few early maturing fish were tagged, and they are omitted here.

Of the early maturing males, all but three surviving fish matured again the next year. The proportions of mature fish in the groups were approximately the same in April 1975 as in November 1974, indicating that no higher mortality had occured among mature than among immature fish during the winter. Mature (spent) fish, tagged in April 1975, showed about 8% lower survival rate until October the same year. This observation is to some extent in contrast to the experience of fish farmers who claim that mature fish show markedly increased mortality during winter and spring.

Observations on growth rate of the early maturing males compared to later maturing fish are summarized in Table 12. Prior to the spawning season (November 1974), when maturing fish could barely be recognized by visual inspection of live fish, the total mean lengths of maturing and immature fish were nearly the same. In April of the next year after the spawing season, mature fish were considerably smaller than immature fish, and also at slaughtering next autumn (October 1975) the early maturing fish (now

Table 12. Growth rate of males maturing at an age of one and a half years, compared to later maturing fish.

$$\bar{l} = \text{mean length},\ r = (\text{growth rate}) = \frac{ln\,\bar{l}_{t_2} - ln\,\bar{l}_{t_1}}{t_2 - t_1}$$

November 74, t_1		April 75, t_2				October 75, t_3					
Maturing	Immature	mature		immature		rematuring			immature		
$\bar{l}$	$\bar{l}$	$\bar{l}$	$r_{t_2-t_1}$	$\bar{l}$	$r_{t_2-t_1}$	$\bar{l}$	$r_{t_3-t_2}$	$r_{t_3-t_1}$	$\bar{l}$	$r_{t_3-t_2}$	$r_{t_3-t_1}$
34.39	34.41	35.95	0.89	41.05	3.52	48.1	4.84	3.05	51.62	3.81	3.68

$t_2 - t_1$ = 5 months, $t_3 - t_2$ = 6 months, $t_3 - t_1$ = 11 months.

mostly re-maturing) were still smaller than fish still immature or maturing for the first time. But the difference was smaller than in April, and converting the figures to specific growth rate (Weatherly 1972), the re-maturing fish showed the higher specific growth rate during summer, but lower both in the winter period and the total period from November to the following October.

DISCUSSION

Koto (1975) found that the mean length of maturing fish was larger than that of immature fish before the spawning season while the immature fish grew faster and reached a higher mean length after the spawning season. He also found higher percentages of early maturing males in groups reared with a larger amount of food, but the percentages of mature fish also seemed to be affected by genetic factors.

From the present investigation it is evident that the percentages of mature fish both in their second and third year of life are affected by genetic factors. (This will be more closely dealt with in later reports when similar results from other year classes also will be dealt with.) Concerning maturation in their third year of life, the analysis of variance has shown that the mean size of maturing fish is greater than of immature fish, and this difference may be traced back 6 months and even a year before onset of maturation.

Difference in growth rate between males and females is more obscure, and it seems to be more pronounced in some sib groups than in others. Differences in growth rate between sib groups are significant, implying that genetic factors are of importance for differences in growth rate. (These observations will also be more closely dealt with in later reports.)

As observed by Koto (1975), the growth rate of early maturing fish was greatly retarded during the spawning season compared to immature fish. However, after the spawning season, the spent fish showed a higher specific growth rate than the others (Table 12), and the length difference at slaughtering was less than half a year before, but the early maturing males did not reach the size of the later maturing fish, and thus they are less valuable for fish farming in spite of their rather high growth rate after the spawning season. Thus it seems clear that rainbow trout used for fish farming in Norway are of varying value both concerning their ability of growth and their age at first maturation, implying that selective breeding may give genetic gain which will be of practical interest.

The present data indicate that males maturing in their second year were of the same mean size before onset of maturation as those maturing later. However, maturation was recognized in live fish in November, and at that time the growth rate of maturing fish could already have been retarded. The present data therefore give no information about whether early maturing fish have a higher mean growth rate during their first year of live, as claimed, a.o., by HALLINGSTAD (1978).

Correlations for individual growth rates were found to be significant for measurements up to one year apart (observations at broader time intervals are lacking). High correlation factors were found between measurements taken half a year apart, and thus selection for individual growth rate may be made after at least one sea year.

As far as could be compared, correlations of mean size of sib groups measured at different ages, were in the same order of magnitude as correlations of individual growth rate. Correlations between the earliest measurements and measurements during the sea period were generally low for the 1972 year class, but somewhat higher for the 1973 year class. As a conclusion it may be said that mean size of the sib groups after a year in the sea (18 months of age) may be used as measurement of the groups ability of growth, but size after one year in the sea (24 months of age) or size at slaughtering (30 months of age) should be preferred for selecting fast growing groups.

REFERENCES

HALLINGSTAD, F. 1978. Sortering og kjønnsmodning hos regnbueørret. *Norsk Fiskeoppdrett, 3* (1): 9–10.

KOTO, T. 1975. The relation between the growth and reproductive characters of rainbow trout, *Salmo gairdneri*. *Bull. Freshwat.Fish. Res.Lab., Tokyo, 25* (2): 83–115.

MØLLER, D., NÆVDAL, G., HOLM, M. and LERØY, R. 1976. Variation in growth rate and age at sexual maturity in rainbow trout. *FAO Technical Conference on Aquaculture, Japan 1976* (E 61): 1–7.

NÆVDAL, G., HOLM, M. and KNUTSSON, S. 1977. Erfaring med bruk av ytre merker på oppdrettsfisk. *Fisken og Havet Ser. B, 1977* (1): 1–21.

NÆVDAL, G., HOLM, M., LERØY, R. and MØLLER, D. 1975. Variation in age at sexual maturity in rainbow trout. *Coun. Meet. int. Coun. Explor. Sea, 1975* (M: 23): 1–7.

WEATHERLY, A. H. 1972. *Growth and ecology of fish populations.* Academic Press, Lnd., N.Y. 293 p.

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GROWTH RATE AND AGE AT SEXUAL MATURITY OF ATLANTIC SALMON SMOLTIFYING AGED ONE AND TWO YEARS

By

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ABSTRACT

NÆVDAL, G., BJERK, Ø., HOLM, M., LERØY, R. and MØLLER, D. 1979. Growth rate and age at sexual maturity of Atlantic salmon smoltifying aged one and two years. *FiskDir. Skr. Ser. HavUnders., 17*: 11–17.

Post-smolt growth rate and age at first maturation are compared for sib groups or population groups of salmon originating from Norwegian rivers and fish farms. Generally, high correlations were found between corresponding values (lengths at different ages and proportions of mature fish in the second and third sea years) for one and two year-old smolt. One year-old smolts were smaller than the two-year olds at the smolt stage and grew slower during their first sea year, but the two categories reached practically the same total length after two years in the sea. In most groups, and in the total material, one year-old smolts gave higher proportions of grilse. Proportions of mature fish during their third sea year were similar for one and two year-old smolt of the same groups. Pronounced variations between sib groups and population groups were found both in growth rate and mean age at first maturation. This variation was much bigger than the variation between one and two year-old smolts of the same sib group.

INTRODUCTION

In Norwegian rivers salmon normally smoltify at 2–5 years-old, depending upon the environmental factors in the rivers, and probably on genetic factors as well (REFSTIE, STEINE and GJEDREM 1977). In commercial rearing of smolt, one year-old smolts are commonly obtained by using heated water, offering good food supply and grading away the smallest individuals after one summer. In Norwegian fish farms about 2/3 of the smolt are now reared in one year and the rest in two years.

It has been widely discussed whether the fast pre-smolt growth rate and early smoltification have some influence on the subsequent growth rate and age at first sexual maturity of the fish. RITTER (1975) and RITTER and NEWBOULD (1977) found significantly lower proportions of grilse in groups of one year-old smolt than in groups of two year-olds or older smolt. Fish farmers have observed that two year-old smolt grow faster and are easier to handle than one year-old smolt the first weeks or months in the sea.

However, most observations suffer from the drawback that fish of different genotypes have been observed. The observations reported here were made on one and two year smolt of the same sib groups, ensuring that similar genotypes could be compared.

MATERIALS AND METHODS

The parent fish in the present investigations were collected from seven rivers and two fish farms in Norway in autumn 1973. Normally two males and two females from each locality were used. The egg portion from each female was divided into two equal parts, each of which was fertilized with sperm from one of the males, thus giving four groups of full sibs from each locality (eight groups from one of the localities).

During fresh water stages the experiments were performed at the Akvakulturstasjonen Matre research station. The eggs and fish were kept in separate trays and parr tanks until they were about six months old (September 1974). Thereafter the groups were kept together two by two in the tank after removing the adipose fin of the fish in one of the groups. In May 1975 the one year-old smolt were marked with freeze-branding (REFSTIE and AULSTAD 1975) and transferred to sea water and later in the summer to the fish farm of Svanøy Stiftelse (Svanøy Foundation), Svanøybukt. The rest of the fish were transferred to brackish water (15–20ppt) in net pens outside the research station in late summer. The next spring (May 1976) nearly all fish smoltified, and after freeze-branding they were transferred to Svanøy Stiftelse. An outbreak of *vibriosis* reduced the number of one year smolt drastically, and many of the groups could not be used in further comparisons. During the sea water stage the fish were length-measured after one year, and at one and a half years, and were slaughtered after about 24 months in the sea. Maturing fish were recorded during the second sea year, and whether or not the fish matured during the third sea years was recorded at slaughtering.

The aim was to select parent fish for the second generation based on the results of the measurements, in order to obtain genetic improvement for fish farming. However, this could not be done because IPN virus was detected in material belonging to the experiments.

The two year-old smolt of the year class hatched in 1973 were kept in similar net pens to the one year smolt at Svanøy Stiftelse, and data from the 1973 year class have therefore been used for comparison.

Standard statistical methods were used for calculations of correlation factors. Per cent values were transformed to $\sin^{-1}\sqrt{\text{proportion}}$ before calculations. Comparisons of corresponding values for one and two year-old smolt were based on the sib groups, but where the numbers of one year-old smolt within groups were low, the sib groups from the same locality were pooled.

RESULTS

GROWTH RATE

Fig. 1 shows main results concerning growth rate. Marked differences between groups were observed.

The mean lengths at the smolt stage were somewhat greater for the 2 year-old smolt than for the one year-old smolt, and after one year in the sea the mean lengths were considerably greater for the 2 year-olds than for the one year-old smolt. For instance, the total mean for the 2 year-old smolt was 42.5 cm against 35.5 cm for the one year-old smolt. However, during the second sea year this difference nearly disappeared, and in many groups the one year-old smolt were larger than the 2 year-old smolt at the end of the second summer. The total mean then showed a difference of 1.7 cm in favour of the 2 year-old smolt. Six months later the two categories were nearly of the same size.

The results were also compared to the mean of the 1973 year class which was composed of 2 year-old smolt and was reared in pens parallel to the one year-old smolt of the 1974 year class. The results of the two year-old smolt of the two year classes were very similar (Fig. 1).

Mean lengths for one and two year-old smolt of the same groups were subjected to a correlation analysis. The following correlation coefficients were found:

smolt:	0.14
one year in the sea:	0.75
one and a half years in the sea:	0.71
two and a half years in the sea:	0.75

Except for the first one, these coefficients are highly significant ($p < 0.01$), implying that each groups has its characteristic post-smolt growth potential regardless of whether they smoltify after one or two years.

AGE AT FIRST SEXUAL MATURATION

The proportions of mature fish observed during second (grilse) and third sea years are shown in Fig. 2. Considerable variation was observed between sib groups and locality groups. Most groups showed higher proportions of grilse among the one year-old smolt than among the two year-old smolt, and the total mean of the one year-old smolt amounted to 23% against 15% for the two year-old smolt. In relation to maturation during the third sea year, good correspondance was generally observed between one and two year-old smolt of the same groups, although some groups diverged somewhat. However, it should be noted that the values of the one year smolt especially are based on few individuals, and rather high sample variation

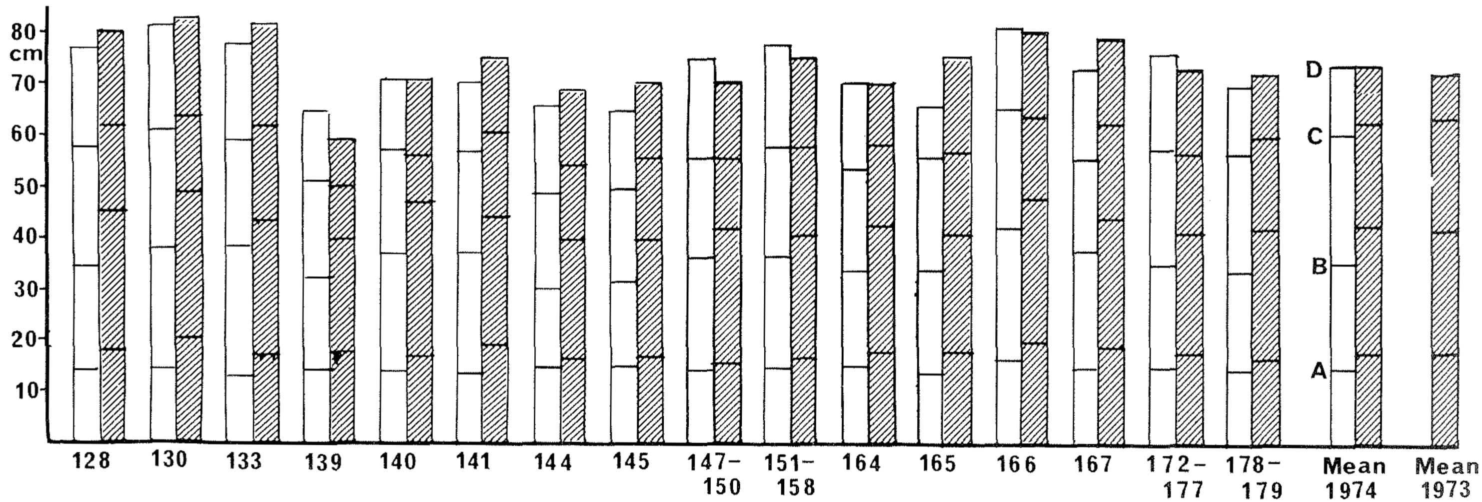

Fig. 1. Mean length of salmon sib groups as smolt (A), after one year (B), after one and a half years (C) and after two years in the sea (D).
Open histograms: one year-old smolt; hatched histograms: two year-old smolt.

may exist. Totally, the two year-old smolt showed a somewhat higher proportion of mature fish during the third sea year.

Corresponding values of one and two year-old smolt of the same groups were subjected to a correlation analysis. The proportions were transformed to $\sin^{-1}\sqrt{\text{proportion}}$ before calculations. The following correlation factors were found:

Maturation second sea year:	0.81
Maturation third sea year:	0.64

Both factors are highly significant ($p < 0.01$), and they show that on an overall basis there is very good correspondance between the results of the two categories. Age at maturation (after smolt stage) thus seems to be a characteristic trait of the groups, although there is a tendency towards higher proportion of grilse among one year-old smolt than among two year-old smolt of the same group. Compared to the two year-old smolt of the 1974 class, both categories of the 1974 year class showed lower proportions of mature fish in both their second and third sea years. This, however, was expected because the 1973 year class contained several groups of a typical grilse population.

DISCUSSION

Differences in post-smolt growth rate between one and two year-old smolt the first sea year was expected, because of the smaller initial size of the one year-old smolt. However, concerning growth rate, one and two year-old smolt are evidently of about the same value for fish farming as they reach the same mean size at the normal time of slaughtering.

The effect of parental age on age at first maturity in Atlantic salmon has been observed by different authors (PIGGINS 1973, RITTER and NEWBOULD 1977, NÆVDAL *et al.* 1978). Genetic factors seem to be very important in determining the age at which the salmon are destined to mature. In the present study considerable variation between sib groups and populations was found, confirming the results of previous studies.

Higher proportions of grilse were observed among one year-old smolt than among two year-olds in most groups, and in the total material. This is somewhat in contrast to the findings of RITTER and NEWBOULD (1977) who found proportionally fewer grilse among one year-olds than among two year-old smolt. The reason for this discrepancy is unknown, but it seems reasonable that different populations may behave differently also in this respect.

HALLINGSTAD (1978) found higher proportions of early maturing rainbow trout among the faster growing than among the slower growing individuals. The fastest growing fish were mostly males, and it is well known that most of

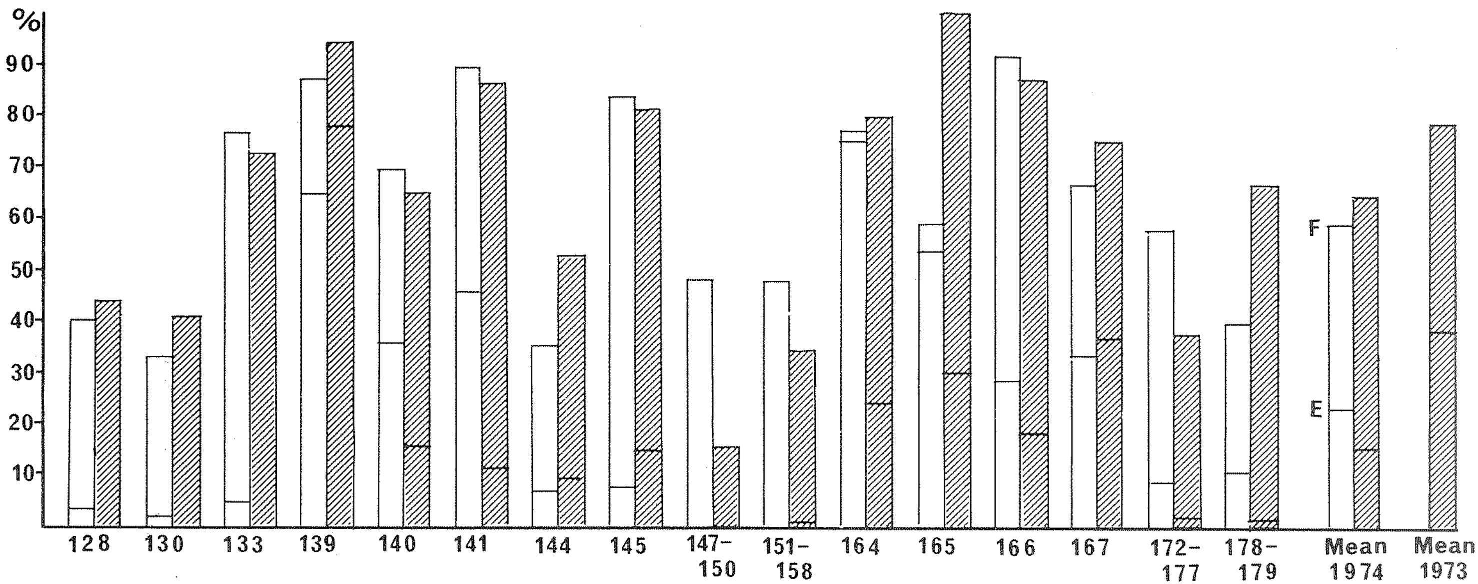

Fig. 2. Proportions of salmon sib groups maturing during their second (E) and third year in the sea (F). Open histograms: one year-old smolt; hatched histograms: two years-old smolt.

the early maturing rainbow trout are males. A similar explanation could not be applied to the present results because the distribution of sexes was nearly the same for the one and two year-old smolt.

One year-old smolt are those fish showing the higher pre-smolt growth rate. If high pre-smolt growth rate causes, or is connected with increased likelyhood of early maturation, or if the fish destined to mature early also show high pre-smolt growth rates, the differences between one and two year-old smolt may be explained. The present experiment can not answer this question, but for practical fish farming it would be important to know if high pre-smolt growth rate also gives high proportions of early maturing fish. If this should be the case, the use of one year-old smolt in fish farming should be questioned.

However, the difference in maturation age between one and two year-old smolt was much smaller than the difference between populations. In some populations there were nearly no grilse, regardless of age of smolt, and selection of such populations for farming could therefore probably solve the problem with grilse among farmed salmon.

REFERENCES

HALLINGSTAD, F. 1978. Sortering og kjønnsmodning hos regnbueørret. Resultater fra høstutsatt regnbueørret i Holmane 1974–1975–1976. *Norsk Fiskeoppdrett, 3* (1): 9–10.

NÆVDAL, G., HOLM, M., MØLLER, D. and INGEBRIGTSEN, O., 1978. Variation in age at first spawning in Atlantic salmon *(Salmo salar) J. Fish.Res.Bd Can., 35*: 145–147.

PIGGINS, D. J. 1973. The result of selective breeding from known grilse and salmon parents. *The Salmon Res. Trust of Ireland Incorporated Ann. Rep. 18*: 35–39.

REFSTIE, T. STEINE, T. A. and GJEDREM, T. 1977. Selection experiments with salmon II. Proportion of Atlantic salmon smoltifying at 1 year of age. *Aquaculture, 10*: 231–242.

REFSTIE, T. and AULSTAD, D. 1975. Tagging experiments with salmonids. *Aquaculture, 5*: 367–374.

RITTER, J. A. 1975. Relationships of smolt size and age with age at first maturity in Atlantic salmon. *Resource Development Branch, Maritimes Region, Environment Can. Tech. Rp.Ser. No. Mar/F-75.5*: 1–7.

RITTER, J. A. and NEWBOULD, K. 1977. Relationship of parentage and smolt age to age at first maturity of Atlantic salmon *(Salmo salar). Coun.Meet.int.Coun.Explor.Sea, 1977* (M32): 1–5.

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THE NORWEGIAN INDUSTRIAL TRAWL FISHERY IN THE NORTH SEA

A study on how the total catch in 1975 could have been increased without exceeding the quotas of cod, haddock and whiting

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ABSTRACT

RØRVIK, C. J. 1979. The Norwegian industrial trawl fishery in the North Sea. A study on how the total catch in 1975 could have been increased without exceeding the quotas of cod, haddock and whiting. *FiskDir. Skr. Ser. HavUnders., 17*: 19–27.

Linear programming is used to demonstrate a way to maximise the total catch in a mixed fishery. Constraints are set by quotas, as well as requirements that the total catch should not be too unevenly distributed between areas and throughout the season. A practical application of this technique in fisheries management depends on a satisfactory prediction of the ratio of the quota-regulated species in the total catch before the season starts.

INTRODUCTION

The Norwegian industrial trawl fishery for Norway pout in the North Sea in 1975 was stopped in November of that year because the quota of whiting had been exceeded by more than 1 000 tonnes. The total catch was 297 000 tonnes, excluding sandeel. The final total landings of bycatch of the quota-regulated species were 1 106 tonnes of cod, 6 942 tonnes of haddock and 15 399 tonnes of whiting.

In 1975 the industrial fishery was unregulated with regard to where and at which time fishing could take place. If there had been quotas, however, for the different fishing grounds in different parts of the season, the total catch could have been substantially larger than 297 000 tonnes, without exceeding the quotas on the regulated species.

The linear programming technique was used in this study. This is a well-known mathematical method in economy which is often used to find an optimal distribution of limited resources. HANSEN (1971) used the method to study the factors determining the economic yield of the Norwegian winter capelin fishery. BROWN, BRENNAN, HEYERDAHL and HENNEMUTH (1973) used linear programming to predict the national catches in ICNAF Subarea 5 and Statistical Area 6. These authors used bycatch ratios of previous years in directed fisheries and national species quotas. GUNDERMAN, LASSEN and NIELSEN (1974) used linear programming to estimate the maximum catch in the North Sea of cod, haddock, whiting, plaice and sole for 31 different fisheries belonging to 11 nations. Besides quotas on each species, they defined rules on how changes in the fisheries should take place.

Rational fisheries management should not only be determined by the possibilities of taking the largest catch within the constraints set by the quotas on the regulated species. Management should also take into account the structure of the fishing fleet, the possibilities of enforcing the regulations, and the state of the species which are not regulated by quotas. These are factors which are disregarded in the present paper. However, the method applied in this study might be a valuable tool for future optimization of industrial fisheries.

MATERIALS AND METHODS

One defines:

$A_{i,j,k}$ = the weight ratio of the species k in the catch in the j^{th} quarter in area i.

$XC_{i,j}$ = the catch in area i, j^{th} quarter.

Of the relevant species, cod, haddock and whiting were quota-regulated in 1975. The weight ratio of these species in the trawl catches for Norway pout are given in Table 1.

The division of the fishing grounds into the three areas is shown in Fig. 1.

The quantity to be maximised is the total catch XC_{TOT}. Thus the objective function is:

$$XC_{TOT} = \sum_{i=1}^{3} \sum_{j=1}^{4} XC_{i,j} \tag{1}$$

The quotas Q_k, have to be respected. This sets the following three constraints, one for each species:

$$\sum_{i=1}^{3} \sum_{j=1}^{4} A_{i,j,k} \cdot XC_{i,j} \leqslant Q_k \; ; \; k=1,2,3 \tag{2}$$

The Norwegian quotas for cod, haddock and whiting in 1975 were 3 000, 10 000 and 14 300 tonnes respectively. Subtracting the quantities used for consumption, one arrives at 1 625 tonnes ($=Q_1$) for cod, 9 678 tonnes ($=Q_2$) for haddock, and 14 238 tonnes ($=Q_3$) for whiting.

Table 1. The weight percentages of cod, haddock and whiting in the Norwegian industrial trawl fishery in the North Sea in 1975. The percentages and the total catches of the industrial trawlers are given for the relevant areas on a quarterly basis.

Area	Quarter j	Cod k=1	Haddock k=2	Whiting k=3	Total catch (tonnes)
The Patch Bank-	1	2.3	3.6	12.6	17 201
Egersund Bank	2	0.4	2.0	1.4	45 155
area	3	0.0	0.1	0.2	25 802
i = 1	4	0.04	0.7	1.2	28 795
Sum					116 953 ($=C_{1.}$)
The Fladen Ground-	1	0.3	9.0	11.7	11 849
Bressay Ground	2	0.3	2.7	20.6	23 746
area	3	0.0	1.3	2.4	65 017
i=2	4	0.1	3.9	10.8	36 574
Sum					137 186 ($=C_{2.}$)
The Tampen-	1	1.3	4.3	1.6	5 354
Viking Bank	2	0.9	2.6	2.7	22 906
area	3	0.3	2.2	3.9	5 335
i=3	4	0.9	2.6	0.8	9 307
Sum					42 902 ($=C_{3.}$)

If the constraints set by (2) were the only constraints, it appears from Table 1 that the highest catch could be achieved by closing all the areas in the North Sea except for the Patch Bank – Egersund Bank area ($i = 1$) in the third quarter when the weight percentages of cod, haddock and whiting were all at a minimum. The maximum catch would be limited by the quota on whiting, that is, 14 238 tonnes $\cdot$ $(100/0.2)$ = 7 119 000 tonnes. However, a total catch of 7.1 mill. tonnes within three months in a relatively small area like the Patch Bank – Egersund Bank area is obviously unrealistic.

Thus, in order to achieve a more realistic distribution of the catches between the areas, the following type of constraints are introduced:

The total yearly catch from the area i ($= \sum_{j=1}^{4} XC_{i,j}$) should not be less than a_i % or greater than b_i % of the actual catch in this area in 1975 ($=C_{i.}$). This rule results in six constraints:

$$\frac{a_i}{100} \cdot C_{i.} \leq \sum_{j=1}^{4} XC_{i,j} \;;\; i = 1,2,3 \qquad (3)$$

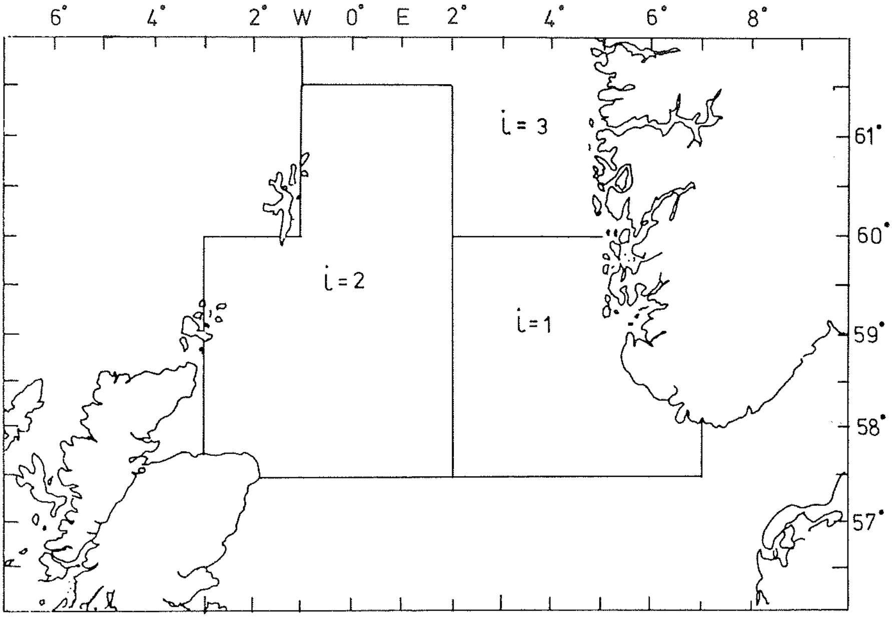

Fig. 1. Fishing grounds of the Norwegian industrial trawlers.
i = 1 The Patch Bank – Egersund Bank area;
i = 2 The Fladen Ground – Bressay Ground area;
i = 3 The Tampen – Viking Bank area.

$$\frac{b_i}{100} \cdot C_{i.} \geqslant \sum_{j=1}^{4} XC_{i,j} \; ; \; i = 1,2,3 \tag{4}$$

$C_{i.}$ values are given in Table 1. In this study a_i is set at 50% and b_i at 150% for all areas. This implies that the total catch will be within ± 50% of the actual total catch in 1975, i.e.

$$148\,500 \text{ tonnes} \leq XC_{TOT} \leq 445\,500 \text{ tonnes}.$$

The sum of the three constraints expressed by (3) can be considered as the minimum catch acceptable for the industry. The sum of the three constraints set by (4) can be considered as the limit set by the amount of effort which can be carried out in this fishery by the existing fleet, and by the available resources.

In order to achieve a more realistic distribution of the catches throughout the season, the requirement that maximum $f_{i,j}$% of the total yearly catch within the area i can be taken within the quarter j, is introduced.

This requirement gives the following 12 constraints which should be fulfilled:

$$XC_{i,j} \leq \frac{f_{i,j}}{100} \cdot \sum_{j'=1}^{4} XC_{i,j'} \;;\; j = 1,2,3,4 \;;\; i = 1,2,3 \qquad (5)$$

Two different constant values of $f_{i,j}$ are used in this study, $f_{ij} = 50\%$ and $f_{i,j} = 33{,}3\%$ for all i and j values.

The objective function given by equation (1) and the constraints defined by (2), (3), (4) and (5) define a problem in linear programming. This mathematical technique is described in most text-books on optimization, for example WALSH (1971). The present study utilized a computer programme from KUESTER and MIZE (1973) which is based on the simplex algorithm.

The outcome of the present optimization problem is catch quotas (irrespective of species) for each area and quarter of the year which give the largest possible total catch within the defined constraints.

RESULTS

Example 1. $f_{i,j} = 50\%$

This value of f in the constraints set by relation (5) implies that an area can not be closed for more than two quarters of the year. Table 2 gives the optimal distribution of the quotas maximising the total catch in the Norwegian trawl fishery for Norway pout.

Table 2 shows that with the constraints (2), (3), (4) and $f_{i,j} = 50\%$ in (5), the total catch could be increased by 43%. This would require that no

Table 2. Example 1. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The number in brackets give the differences compared with the actual catches in 1975.

Quarter	Area: The Patch Bank-Egersund Bank area i=1	Area: The Fladen Ground-Bressay Ground area i=2	Area: The Tampen-Viking Bank area i=3	Total
1	0 (−100%)	0 (−100%)	32 250 (+502%)	32 250 (− 6%)
2	0 (−100%)	0 (−100%)	0 (−100%)	0 (−100%)
3	87 750 (+240%)	92 693 (+ 43%)	0 (−100%)	180 443 (+ 88%)
4	87 750 (+205%)	92 693 (+153%)	32 250 (+247%)	212 693 (+185%)
Total	175 500 (+ 50%)	185 386 (+ 35%)	64 500 (+ 50%)	425 386 (+ 43%)

industrial trawling was allowed in the Patch Bank – Egersund Bank area and in the Fladen Ground – Bressay Ground area in the first half of the year. The Tampen – Viking Bank area would have to be closed in the second and third quarters.

The by-catch of the quota-regulated species would have been 837 tonnes of cod, 7 748 tonnes of haddock, and 14 238 tonnes of whiting (= the quota). The quota of whiting is the limiting factor.

Example 2. $f_{i,j} = 33.33\%$

This value of $f_{i,j}$ implies that an area can be closed for no more than one quarter. Table 3 gives the optimal quota allocation.

Table 3. Example 2. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area			Total
	The Patch Bank-Egersund Bank area i=1	The Fladen Ground-Bressay Ground area i=2	The Tampen-Viking Bank area i=3	
1	0 (−100%)	44 675 (+277%)	5 006 (− 6%)	49 681 (+ 44%)
2	58 500 (+ 30%)	0 (−100%)	21 500 (− 6%)	80 000 (− 13%)
3	58 500 (+127%)	44 675 (− 31%)	16 494 (+209%)	119 669 (+ 24%)
4	58 500 (+103%)	44 675 (+ 22%)	21 500 (+131%)	124 675 (+ 67%)
Total	175 500 (+ 50%)	134 025 (− 2%)	64 500 (+ 50%)	374 025 (+ 26%)

The change of $f_{i,j}$ from 50% to 33.33% would result in a decrease of the maximum possible catch by 51 361 tonnes to 374 025 tonnes. The by-catch would be 938 tonnes of cod, 9 678 tonnes of haddock (= the quota) and 14 238 tonnes of whiting (= the quota).

Tables 2 and 3 give the maximum catch which could be taken in areas 1 and 3, that is 150% (= b_i in relation (4)) of the actual catch in 1975. Only in area 2 is it possible to increase the catches without violating relation (4).

TRANSFERABLE QUOTAS

According to an agreement in the North-East Atlantic Fisheries Commission (NEAFC), any Contracting State was allowed to transfer up to 3 000 tonnes between the quotas of cod, haddock and whiting in 1976.

Example 3

Example 1 was re-calculated with a reduction of 600 tonnes in the cod quota, a reduction of 1 000 tonnes in the haddock quota, and an increase of 1 600 tonnes in the whiting quota. The quotas then became 1 025 tonnes of cod, 8 678 tonnes of haddock and 15 838 tonnes of whiting. The results are given in Table 4.

Table 4. Example 3. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area						Total	
	The Patch Bank-Egersund Bank area i=1		The Fladen Ground-Bressay Ground area i=2		The Tampen-Viking Bank area i=3			
1	0	(−100%)	0	(−100%)	7 477	(+ 40%)	7 477	(− 78%)
2	0	(−100%)	0	(−100%)	24 773	(+ 8%)	24 773	(− 73%)
3	87 750	(+240%)	102 750	(+ 58%)	0	(−100%)	190 500	(+ 98%)
4	87 750	(+205%)	102 750	(+181%)	32 250	(+247%)	222 750	(+198%)
Total	175 500	(+ 50%)	205 500	(+ 50%)	64 500	(+ 50%)	445 500	(+ 50%)

The amounts of cod, haddock and whiting caught with the catch distribution given in Table 4 would be 748, 7 850 and 15 838 tonnes (= the quota) respectively.

The transfer of 1 600 tonnes from the cod and haddock quotas to the whiting quota would increase the maximum catch from 425 386 tonnes (Table 2) to 445 500 tonnes (Table 4). An additional increase in the total catch is not possible since relation (4) sets a maximum of 445 500 tonnes for b_i at 150%.

Example 4

Example 2 was re-calculated with a reduction of 600 tonnes on the cod quota, an increase of the haddock quota by 250 tonnes and the whiting quota by 350 tonnes. The quotas thus became 1 025 tonnes of cod, 9 928 tonnes of haddock and 14 588 tonnes of whiting. The results are given in Table 5.

The amounts of cod, haddock and whiting caught in this example would be 959, 9 928 (= the quota) and 14 588 tonnes (= the quota) respectively.

Example 2 gave the conditions which allowed the least increase (+ 26%) in the total catch. The transfer of quotas in example 4 would only increase

Table 5. Example 4. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area: The Patch Bank-Egersund Bank area i=1	Area: The Fladen Ground-Bressay Ground area i=2	Area: The Tampen-Viking Bank area i=3	Total
1	0 (−100%)	46 217 (+290%)	6 483 (+ 21%)	52 700 (+ 53%)
2	58 500 (+ 30%)	0 (−100%)	21 500 (− 6%)	80 000 (− 13%)
3	58 500 (+127%)	46 217 (− 29%)	15 017 (+181%)	119 734 (+ 25%)
4	58 500 (+103%)	46 217 (+ 26%)	21 500 (+131%)	126 217 (+ 69%)
Total	175 500 (+ 50%)	138 651 (+ 1%)	64 500 (+ 50%)	378 651 (+ 27%)

the maximum catch by 4 626 tonnes when the other conditions were as in example 2. Only a small additional increase of the maximum catch is possible since no more than 66 tonnes of the cod quota would remain unfished in example 4.

DISCUSSION

The constraints set by the relation (5) imply that the catches would be distributed throughout the season. One could have required explicitly that the catch within the j^{th} quarter of the year should at least be of a certain minimum size $C_{min,j}$, i.e.:

$$\sum_{i=1}^{3} XC_{i,j} \geq C_{min,\ j} \tag{6}$$

If, instead, the requirement is that at least $d\%$ of the total catch should be taken within the j^{th} quarter of the year, the mathematical relation would be:

$$\sum_{i=1}^{3} XC_{i,j} \geq \frac{d}{100} \cdot XC_{TOT} \tag{7}$$

The objective function (1) is the total catch in tonnes. Instead of maximising the weight of the catch, the value of the catch could have been maximised. The objective function would then be:

$$\sum_{i=1}^{3} \sum_{j=1}^{4} V_{i,j} \cdot XC_{i,j} \tag{8}$$

where $V_{i,j}$ is the value per unit weight of the catch from area i, in the j^{th} quarter. These two objective functions, (1) and (8), would probably result in two different optimal quota allocations unless $V_{i,j}$ is the same for all i and j values.

An assumption in this study is that the relative catch compositions (Table 1) are constant within the time intervals and the areas (Fig. 1) used. This is a crude approximation. It is not a problem from the mathematical point of view to use more and smaller time and area units than those used in the present study, but it becomes more difficult to get reliable data for the catch composition when refinements of the time and area units are introduced.

It is also assumed in this study that the relative catch compositions are independent of the size of the catches in the different areas through the year. The goodness of this assumption weakens as the hypothetical catches (Table 2–5) depart from the real 1975 catches.

If this method is to have any practical application in fisheries management, a main problem is to satisfactorily predict, before the season starts, the ratio of the quota-regulated species in the catch at the different grounds in each part of the season. This problem, however, is outside the scope of the present paper.

REFERENCES

BROWN, B. E., BRENNAN, J. A., HEYERDAHL, E. G. and HENNEMUTH, R. C. 1973. Effect of by-catch on the management of mixed species fisheries in Subarea 5 and Statistical Area 6. *Redbook int. Commn NW. Atlant. Fish., 1973* (3): 217–231.

GUNDERMANN, J., LASSEN, H. and NIELSEN, E. 1974. Splitting catch quotas of several species on a number of fisheries using linear programming. *Coun. Meet. int. Coun. Explor. Sea, 1974* (F 46): 1–13. [Mimeo.]

HANSEN, T. 1971. An analysis of the factors determining the economic yield of the winter capelin fishery by means of a mathematical model. Organization for Economic Co-operation and Development. *International Symposium on Fisheries Economics, FI/T(71)1/47*: 1–14.

KUESTER, J. L. and MIZE, J. H. 1973. *Optimization techniques with Fortran.* McGraw-Hill Book Company, London. 500 p.

WALSH, G. R. 1971. *An Introduction to Linear Programming.* Holt, Rinehart and Winston Ltd., London. 214 p.

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