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# The estimation of efficient use of fish stocks, a simple method of showing how a fishery should be carried out to get the highest output from the fish stocks

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From 1 June 1967 or the date on which the 1961 ICNAF recommendation for Subareas 1, 2 and 3 comes into effect for Subarea 1 (West Greenland), whichever date is later, codends of trawl nets of at least 130 mm manila (120 mm nylon) mesh-size must be used. This resolution was passed at the 1966 ICNAF meeting in Madrid. Thus, for the first time a legal mesh regulation will be in force for the trawl fishery in Subarea 1. What developments led to this regulation, and what is achieved by it?

## 1. Recent Development of the Cod Fishery in ICNAF Subarea 1

In the last few years, the cod fishery off West Greenland has increased considerably. During the years 1952-1960, the average annual nominal catch was 277,000 metric tons, whereas in the 5 year period from 1961-1965, the average annual catch was 382,000 tons, an increase of 38%, with a maximum of 451,000 tons in 1962. The increase in yield was, to a large extent, due to increased trawler activity and to the intensification of the Greenland fishery by the Federal Republic of Germany which, since 1961, has been the leading fishing nation in Subarea 1. The increase in yield was not a consequence of greater stock density, but it resulted from a strong intensification of the fishing effort. In spite of the use (input) of more and more efficient fishing vessels the catch per unit has declined continually since 1962 (see the 1966 German Research Report, ICNAF Res. Doc.67/14).

The intensive fishery first reduced the stock of big cod, thus affecting especially the salt fish production dependent upon big cod. The decrease in yield of big cod was compensated by an enforced fishing of the young cod stocks. This resulted in a more rapid reduction of the year-classes entering the fishery and, having regard to the high rate of growth of West Greenland cod, a very unprofitable utilization of this stock. The stock of young cod was reduced primarily in recent years by the ever increasing activity of the factory trawlers (especially when these converted from the Baader filleting machines type 99 to the Baader 338 for small cod). The factory trawlers were also able to process in their big fish meal plants the big catches of small cod which occurred frequently and which were useless for filleting in spite of Baader 338.

In order to reduce, in the interest of all nations participating in the Greenland fishery, the uneconomical catching of young fish by trawlers, the Danish delegation at the 1965 ICNAF meeting in Halifax proposed closing Great Halibut Bank, one of the main growth areas for young West Greenland cod, to fishing by trawlers. The "ICNAF Greenland Cod Working Group", composed of fishery biologists from Denmark, United Kingdom, Portugal, USSR and the Federal Republic of Germany, was asked to study the effects on the international Greenland fishery of a regulation of this type. The resulting investigations showed that closing Great Halibut Bank (Div.1B) could produce a beneficial effect on all methods of fishing (trawl, longline, handline). The Working Group also showed that greater profits could eventually result for all fishing nations if, at the same time, a mesh size of 150 mm manila were introduced. After long discussions at its 1966 meeting, the Commission adopted only the proposals of the biologists to introduce for Greenland a mesh size of 130 mm manila (120 mm nylon).

The following investigations will show to what extent Greenland cod had been used, to what extent they could be used, and what will be achieved by using a mesh size of 130 mm.

## 2. Growth and Rate of Growth

In contrast to Labrador cod, which are slow growing, West Greenland cod grow extremely fast, especially in the years before maturity. It is remarkable that, since 1960/61, Greenland cod have had a faster growth rate (Table 1). The

Table 1. Mean length and mean weight of gutted West Greenland cod at the end of December in the years 1953-1960 and 1961-1965

| Age | 1953-1960 | | 1961-1965 | | Percentage increase in weight 53/60 to 61/65 |
|---|---|---|---|---|---|
| | cm | g | cm | g | |
| 2 years (end of 3rd feeding period) | ? | - | 32 | 250 | - |
| 3 years (end of 4th feeding period) | 40 | 510 | 44 | 670 | 31 |
| 4 years (end of 5th feeding period) | 49 | 915 | 54 | 1,260 | 38 |
| 5 years (end of 6th feeding period) | 58 | 1,555 | 64.5 | 2,035 | 31 |
| 6 years (end of 7th feeding period) | 67 | 2,250 | 71.5 | 2,705 | 20 |
| 7 years (end of 8th feeding period) | 70 | 2,540 | 76.5 | 3,290 | 30 |
| 8 years (end of 9th feeding period) | 73.5 | 2,930 | 80.5 | 3,820 | 30 |
| 9 years (end of 10th feeding period | 75 | 3,100 | 84.0 | 4,360 | 41 |
| 10 years (end of 11th feeding period) | 77 | 3,475 | 86.0 | 4,680 | 35 |
| | | | | | 32% |

faster rate of growth has resulted in an increased average weight of 32% for the individual age-groups. Since there has been no decisive improvement of the climate off Greenland in the last few years and, on the contrary, many facts indicate rather a deterioration of the climatic conditions, it can be supposed that the abrupt increase in growth in 1961 is intrinsically related to the increased intensity of the Greenland fishery since that time. As a result more food is available today for the highly reduced stock than in previous years with higher stock density. That a causal relationship exists between stock density and growth off Greenland is suggested by the fact that the extremely strong 1947 year-class showed an extremely reduced growth rate due to competition for food.

## 3. Weight and Natural Mortality

Table 2 shows that 1,000 2-year-old cod at the end of their 3rd feeding period weigh 250 kg (fresh gutted weight). Knowing that the natural rate of mortality of West Greenland cod is 15 to 20%, let us assume that the annual reduction by natural causes is 20%. Therefore, of the 1,000 2-year-old cod, 200 are eliminated by death, predation by bigger animals, illness, etc. one year later at the end of their 4th feeding period. The individual weights of the remaining 800 animals, however, have increased from 250 g to 670 g, that is more than 1 1/2 fold; of the 1,000 2-year-old cod are still alive. Their individual weights have now giving a total weight of 536 kg. At the end of the 5th feeding period, only 6~~0~~0 4 increased by 590 g to 1,260 g, and they now weigh a total of 806 kg. Table 2 shows that the total weight, based on an annual mortality rate of 20%, increases to 1,109 kg at the end of the 7th feeding period.

Table 2. Gutted weight of the stock of West Greenland cod in dependency on age and natural mortality of 20%.

| Age | g | number of fish | Stock weight kg | % of maximum weight |
|---|---|---|---|---|
| 2 years (end of 3rd feeding period) | 250 | 1,000 | 250 | 23 |
| 3 years (end of 4th feeding period) | 670 | 800 | 536 | 48 |
| 4 years (end of 5th feeding period) | 1,260 | 640 | 806 | 72 |
| 5 years (end of 6th feeding period) | 2,035 | 512 | 1,042 | 94 |
| 6 years (end of 7th feeding period) | 2,705 | 410 | 1,109 | 100 |
| 7 years (end of 8th feeding period) | 3,290 | 328 | 1,079 | 97 |
| 8 years (end of 9th feeding period) | 3,820 | 262 | 1,001 | 90 |
| 9 years (end of 10th feeding period) | 4,360 | 210 | 916 | 83 |
| 10 years (end of 11th feeding period) | 4,680 | 168 | 786 | 71 |
| 11 years (end of 12th feeding period) | 4,920 | 134 | 659 | 59 |
| 12 years (end of 13th feeding period) | 5,155 | 107 | 552 | 50 |
| 13 years (end of 14th feeding period) | 5,350 | 86 | 460 | 41 |

After the 6th and 7th feeding periods, West Greenland cod start spawning for the first time. The annual weight increment of individual mature cod is still considerable, but it is less than that during the immature stage, because much of the food intake is now needed for maturation of the gonads, for the spawning migration, and for the spawning process and only the remaining small part can be used for body growth. After the 9th feeding period, the total weight of the remaining 262 cod is still over 1,000 kg which is 90% of the greatest total weight. With progressing age, however, the total weight decreases rapidly as is shown in Table 2 and by the hatched curve in Fig. 1.

From calculations of population dynamics, it is known that natural mortality decreases with age since the number of predators decreases with increase in body size of the cod. For this reason, the same calculations, as in Table 2, were also carried out using other rates of natural mortality. Table 3 shows the changes in total weight when natural mortality is 25% to start with, then 20%, and from the 6th feeding period on is 15%. The dotted line in Fig. 1 shows that, in principle, the same growth curve is obtained. In this case, the maximum weight of 1,214 kg is reached one year later.

Table 3. Gutted weight of the stock of West Greenland cod in dependency on age and natural mortality decreasing from 25 and 20 to 15%.

| Age | g | mortality | Stock number of fish | Stock weight kg | % of maximum weight |
|---|---|---|---|---|---|
| 2 years (end of 3rd feeding period) | 250 | | 1,000 | 250 | 21 |
| | | 25% | | | |
| 3 years (end of 4th feeding period) | 670 | | 750 | 503 | 41 |
| | | 20% | | | |
| 4 years (end of 5th feeding period) | 1,260 | | 600 | 756 | 62 |
| | | 15% | | | |
| 5 years (end of 6th feeding period) | 2,035 | | 510 | 1,038 | 86 |
| | | 15% | | | |
| 6 years (end of 7th feeding period) | 2,705 | | 434 | 1,174 | 97 |
| | | 15% | | | |
| 7 years (end of 8th feeding period) | 3,290 | | 369 | 1,214 | 100 |
| | | 15% | | | |
| 8 years (end of 9th feeding period) | 3,820 | | 314 | 1,199 | 99 |
| | | 15% | | | |
| 9 years (end of 10th feeding period) | 4,360 | | 267 | 1,164 | 96 |
| | | 15% | | | |
| 10 years (end of 11th feeding period) | 4,680 | | 227 | 1,062 | 87 |
| | | 15% | | | |
| 11 years (end of 12th feeding period) | 4,920 | | 193 | 950 | 78 |
| | | 15% | | | |
| 12 years (end of 13th feeding period) | 5,155 | | 164 | 845 | 70 |
| | | 15% | | | |
| 13 years (end of 14th feeding period) | 5,350 | | 139 | 744 | 61 |

Table 4 and the solid line in Fig. 1 show what is probably closest to the true natural mortality. In this case, as in Table 3, for the first two years a natural mortality of 25% and 20% was chosen. For the following years, however, a mortality which decreases by 1% per annum from 18% down to 10% was chosen as a base. The resulting growth curve (graph) lies about midway between the two curves already described.

Table 4. Gutted weight of the stock of West Greenland cod in dependency on age and natural mortality decreasing from 25 and 20 to 18 - 10%.

| Age | g | mortality | Stock: number of fish | Stock: Wt kg | Stock: % of maximum weight |
|---|---|---|---|---|---|
| 2 years (end of 3rd feeding period) | 250 | | 1,000 | 250 | 22 |
| | | 25% | | | |
| 3 years (end of 4th feeding period) | 670 | | 750 | 503 | 45 |
| | | 20% | | | |
| 4 years (end of 5th feeding period) | 1,260 | | 600 | 756 | 67 |
| | | 18% | | | |
| 5 years (end of 6th feeding period) | 2,035 | | 492 | 1,001 | 89 |
| | | 17% | | | |
| 6 years (end of 7th feeding period) | 2,705 | | 408 | 1,104 | 98 |
| | | 16% | | | |
| 7 years (end of 8th feeding period) | 3,290 | | 343 | 1,128 | 100 |
| | | 15% | | | |
| 8 years (end of 9th feeding period) | 3,820 | | 292 | 1,115 | 99 |
| | | 14% | | | |
| 9 years (end of 10th feeding period) | 4,360 | | 251 | 1,094 | 97 |
| | | 13% | | | |
| 10 years (end of 11th feeding period) | 4,680 | | 218 | 1,020 | 90 |
| | | 12% | | | |
| 11 years (end of 12th feeding period) | 4,920 | | 192 | 945 | 84 |
| | | 11% | | | |
| 12 years (end of 13th feeding period) | 5,155 | | 171 | 882 | 78 |
| | | 10% | | | |
| 13 years (end of 14th feeding period) | 5,350 | | 154 | 824 | 73 |

## 4. Efficient Use and the "Ideal Fishery"

In spite of the different natural mortality rates, all three curves in Fig. 1 show a surprisingly similar trend. They each have a very steep ascent and, after the end of the 6th feeding period when maturity begins, they have a more or less flat peak. This total weight curve is of essential importance in answering the question of how to exploit the West Greenland cod stock most profitably. It shows quite clearly that, in determining the greatest total weight which a cod year-class can contribute during its life-span to the Greenland fishery, growth rate is much more important than natural mortality rate. The value of the conclusions which can be derived for the fishery from this curve are, however, of fundamental importance. The natural mortality rate - less important in this case - can only be determined approximately by indirect mathematical methods of calculation. The growth rate, however - much more important in this case - can be determined with high precision from length measurements and age determinations (there is no difficulty in aging West Greenland cod). Therefore, the following well-founded statements can be made regarding the rational and economic management of the West Greenland cod fishery:

1. The highest possible fishing yield would be obtained if the cod were caught in their 8th year of life as 7-year-old fish.
2. Catching the cod before and after their 8th year of life will reduce the efficient use of the stock.
3. The utilization of this natural source of protein is especially low if the cod are caught as 2-, 3-, and 4-year-old fish.
4. A highly efficient use of the stock (more than 90%) is obtained if the cod are caught at 6 to 9 years of age.
5. The "ideal fishery", the one with the highest total weight yield, prohibits the taking of cod less than 6 years of age yet is so intensive that no cod reaches 10 or more years of age.

To express these ideal postulates as body length in cm, it is necessary to convert the ages into length measurements. If the values for the respective efficiency of use (% of maximum weight) obtained from Table 4 are related to the mean lengths for the different ages as given in Table 1, the curve for the efficiency of use in relation to body length is obtained (Fig. 2). Table 5 shows the corresponding figures for the efficient use of the stock for each 3 cm length-groups, which can be deduced from the curve in Fig. 2. The values exceeding 90% for efficient use of the fish stock - as Fig. 2 indicates quite clearly - are reached by taking cod between 65 and 86 cm of length. The fifth statement above must, therefore, be expressed in terms of fish length and be read as follows:

The fishery off West Greenland would yield more than 90% of the maximum weight produced if no cod less than 65 cm long were caught and if the fishing effort of trawls and lines were so intensive that all big cod were caught before they reached a length of 87 cm.

International efforts to regulate the fishery off West Greenland should, therefore, aim to come as near as possible to this "ideal" of a cod fishery.

Table 5. Efficiency of stock use in relation to body length (3 cm groups)

| Body length | Efficiency |
|---|---|
| 24-26 cm | 13% |
| 27-29 cm | 17% |
| 30-32 cm | 21% |
| 33-35 cm | 26% |
| 36-38 cm | 31% |
| 39-41 cm | 37% |
| 42-44 cm | 43% |
| 45-47 cm | 50% |
| 48-50 cm | 57% |
| 51-53 cm | 63% |
| 54-56 cm | 70% |
| 57-59 cm | 77% |
| 60-62 cm | 83% |
| 63-65 cm | 89% |
| 66-68 cm | 93% |
| 69-71 cm | 97% |
| 72-74 cm | 99% |
| 75-77 cm | 100% |
| 78-80 cm | 100% |
| 81-83 cm | 98% |
| 84-86 cm | 92% |
| 87-89 cm | 80% |
| 90-92 cm | 67% |
| > 92 cm | 50% |

5. The efficiency of stock use, to the present, in the Greenland cod fishery

Table 5 makes it possible, by a simple combination of its percentage efficiency figures with a per mille row of length measurements of a catch made off Greenland, to establish the degree to which a certain method of fishing, either by trawl or by longlines and handlines, utilizes the stock with regard to the quantity of meat it offers for human consumption. Some examples, taken in this case from the German trawl fishery, will give the details.

a) Fishery for pre-spawning concentrations

In January 1967, the German fleet after a long period of very poor catches, fished with very good results in the area of Banan and Fyllas Banks. Determinations of age and maturity showed that the concentrations consisted mainly of shoals of pre-spawners and among them some bigger immature cod. Table 6 shows that about 60% of the cod fished in this area belonged to the rich 1961 year-class (age 6 years), 65% of which were preparing for spawning for the first time. Over 20% of these fish were from the 1960 year-class (age 7 years) and were first and second time spawners. The older year-classes, all of which had spawned several times, contributed another 7%. The remainder was made up of 5-year-old cod of the 1962 year-class and were almost exclusively immature cod. No 2- and 3-year-old cod were found in these winter concentrations. The average length was 66.1 cm. Range in length was 47 to 104 cm. The average weight of the fresh gutted fish was 2,260 g with 77% of the catch in market class II (medium). All cod caught were utilized; none had to be turned into fish meal. Calculating the value for the efficiency of stock use from the figures in Table 5 and from the length composition in Table 6, the result is 88.0%. This means that, for this catch composition, 88% of the possible maximum weight for West Greenland cod were obtained. From the point of view of gaining cod flesh (protein production from the sea), this fishery on concentrations of pre-spawners mixed with a certain quantity of older juvenile cod readily qualifies.

Table 6. Length and age composition (‰) of samples from West Greenland.

| | Banan-Fyllas Bk Jan 67 | Banan Bk Mar 66 | Holsteinsborg Nov 65 | Nanortalik Nov 64 | Thorvaldsen A.Dohrn Oct 66 | Thorvaldsen Fact.Traw. Oct 66 |
|---|---|---|---|---|---|---|
| mesh size/mm | 110 | 110 | 60 | 110 | 60 | ≈80 |
| Length groups | | | | | | |
| 24-26 | - | - | 2 | - | 5 | 3 |
| 27-29 | - | - | 15 | 2 | 14 | 5 |
| 30-32 | - | - | 42 | 5 | 17 | 12 |
| 33-35 | - | - | 54 | 13 | 45 | 37 |
| 36-38 | - | - | 87 | 50 | 111 | 103 |
| 39-41 | - | - | 116 | 134 | 133 | 125 |
| 42-44 | - | - | 118 | 218 | 124 | 136 |
| 45-47 | 1 | - | 97 | 204 | 119 | 146 |
| 48-50 | 8 | 3 | 79 | 89 | 101 | 108 |
| 51-53 | 35 | 16 | 62 | 24 | 82 | 87 |
| 54-56 | 45 | 34 | 52 | 15 | 78 | 74 |
| 57-59 | 109 | 103 | 53 | 21 | 70 | 56 |
| 60-62 | 128 | 127 | 52 | 30 | 53 | 41 |
| 63-65 | 192 | 117 | 49 | 33 | 26 | 25 |
| 66-68 | 178 | 151 | 40 | 34 | 12 | 21 |
| 69-71 | 116 | 108 | 25 | 27 | 6 | 5 |
| 72-74 | 87 | 104 | 17 | 35 | 1 | 6 |
| 75-77 | 44 | 69 | 14 | 19 | 1 | 4 |
| 78-80 | 24 | 56 | 11 | 18 | 1 | 2 |
| 81-83 | 12 | 25 | 7 | 13 | 1 | - |
| 84-86 | 10 | 25 | 5 | 10 | - | 1 |
| 87-89 | 4 | 18 | 2 | 3 | - | 2 |
| 90-92 | 4 | 14 | 1 | 1 | - | 1 |
| 93-95 | 2 | 8 | - | 1 | - | - |
| 96-98 | 1 | 5 | - | - | - | - |
| 99-101 | - | 6 | - | - | - | - |
| 102-104 | - | 5 | - | - | - | - |
| 105-107 | - | 3 | - | - | - | - |
| 108-110 | - | 2 | - | - | - | - |
| 111-113 | - | 1 | - | - | - | - |
| av. length | 66.1 | 69.5 | 49.7 | 50.8 | 46.8 | 48.0 |
| Age (year-class in parentheses) | | | | | | |
| 2 | - | - | 78 (63) | 4 (62) | 27 (64) | 13 (64) |
| 3 | - | - | 335 (62) | 697 (61) | 241 (63) | 223 (63) |
| 4 | 4 (63) | - | 267 (61) | 39 (60) | 318 (62) | 343 (62) |
| 5 | 137 (62) | 49 (61) | 216 (60) | 39 (59) | 407 (61) | 404 (61) |
| 6 | 590 (61) | 501 (60) | 32 (59) | 130 (58) | 3 (60) | 3 (60) |
| 7 | 206 (60) | 123 (59) | 10 (58) | 33 (57) | 1 (59) | 3 (59) |
| 8 | 21 (59) | 66 (58) | 61 (57) | 50 (56) | 3 (58) | 8 (58) |
| 9 | 0 | 179 (57) | - | - | 0 | 0 (57) |
| 10 | 34 (57) | 14 (56) | - | - | 0 | 2 (56) |
| 11 | 1 (56) | 6 (55) | - | 4 (53) | - | - |
| 12 | 0 | 2 (54) | 1 (53) | - | - | - |
| 13 | 4 (54) | 45 (53) | - | - | 0 | 0 |
| 14 | 3 (53) | 6 (52) | - | - | - | - |
| 15 | 0 | 8 (51) | - | 2 (49) | - | 1 (51) |
| 16 | - | - | - | - | - | - |
| 17 | - | - | - | 2 (47) | 0 | 0 |
| 18 | - | - | - | - | - | - |
| 19 | - | 1 (47) | - | - | - | - |

b) Fishery for spawning concentrations

The question now arises: is there a fishery in which a still higher utilization of the stocks can be attained? One might think that catches of concentrations of cod consisting exclusively of spawners and in which juvenile cod are completely lacking, ought to give the highest efficiency of stock use.

To now a cod fishery for spawners off Greenland could only be carried out in very rare cases. Off West Greenland cod spawn mainly below 500 m since at depths of 600-800 m the water is warmest due to the warm Atlantic component of the West Greenland Current. To fish along the steep slope of the shelf between Fyllas and Frederikshaab Banks below 500 m has been impossible up to the present time. But, to the west of Banan Bank, the slope is less steep. Here to the west of Little and Great Halibut Banks, the Baffinland Ridge separates the deep waters of Baffin Bay and the Labrador Sea and fishing can be carried out on the gentle slopes even below 500 m. In March/April 1961, for the first time, shoals of spawning cod were discovered here. Here, too, in March 1966, along the southern slope of Baffinland Ridge, pure shoals of spawners provided very profitable fishing down to 600-750 m. About 50% of the spawning cod were of the good 1960 year-class, which in 1966 spawned for the first time (Table 6). The rich 1957 year-class still contributed 18% and the previously rich 1953 year-class 4.5%. The average length of the spawning cod was 69.5 cm (50-130 cm long). The average weight was 2,680 g, and 23% of the landings consisted of market class I and "giants".

In spite of the fact that only mature fish were caught, the efficiency of stock use in this fishery was only 88.3% - the same as in the fishery for the pre-spawning concentrations. The explanation for this lies in the fact that there was a high proportion of cod 10 and more years of age in the fishery. From the point of view of maximum and rational exploitation, these fish were caught too late in life.

c) Fishery in growth areas for young fish

A typical fishery in an area with a high proportion of juvenile cod is in Holsteinsborg Deep at the southern end of Great Halibut Bank. From the mesh selection experiments of the R/V Walther Herwig in November 1965 in this area, extremely exact determinations can be made about the composition of the stock there. From the selection values (selection factor 3.3, selection range 9 cm) the effect of fishery with different mesh sizes can be calculated with precision. In November in the Holsteinsborg Deep a trawler using a codend with a mesh size of 110 mm and with no chafer to affect the selectivity could only attain an efficiency of stock use of 61%. However, great quantities of cod, much smaller than 40 cm, would be caught (selection range for 110 mm is from 32 to 41 cm). Thus, even factory ships fitted with filleting machines for small cod (Baader 338) can only use 68% of the fish caught for filleting. The remaining 32% are converted directly to fish meal. In practise, however, because of the effect of chafers and of nets with mesh-sizes smaller than 110 mm the percentage of smaller cod is higher and the efficiency of stock use accordingly lower. To the present, no mesh regulations have been in force for West Greenland and, as has been confirmed by the many very small-meshed codends of at best 80 mm which have been recovered from the bottom, it is nearly impossible for the very smallest cod to escape capture. For the 80 mm mesh size of codend, an efficiency of stock use of only 57% was calculated, and for factory ships provided with Baader 338 filleting machines the proportion of cod turned directly into fish meal accordingly rises to more than 40%.

Results of the age investigations (Table 6) show why the efficiency of stock use in the fishery off Holsteinsborg is so low while, at the same time, the proportion of so-called "industrial" cod is so high. In November 1965, only 10.4% of the cod were older than 5 years. Even if the fishery were carried out with a mesh-size of 110 mm and without any chafer, at best no more than 11% of the smallest cod could escape.

However, not only are juvenile cod caught too early (from the point of view of best use and most profit) on the Great Halibut Bank but on all of the fishing grounds along the coast of West Greenland. Thus, the efficiency of stock use on Fyllas Bank at the end of 1964 when the 1961 year-class reached catchable sizes for the first time only amounted to 58%. Here, 62% of the fishes caught by the 110 mm size of mesh (without chafer) were only 3 years old. In the area of Nanortalik Bank the proportion of this year-class taken even reached 70% (Table 6). However, 22% of the cod caught were more than 5 years old resulting in an efficiency of stock use which was still only 57%.

Selection experiments made in October 1966 from R/V Anton Dohrn and catch studies on board a factory ship operating on the same fishing grounds confirm that because of the blockage of meshes by chafers and the use of very small mesh sizes, etc. there is little effective selection. This is shown clearly in Fig. 3. The solid line in Fig. 3 shows the length distribution of the cod caught by Anton Dohrn in October 1966 off Thorvaldsen using a 60 mm mesh size of net over the codend. Since at best only 0- and 1-year-old cod can escape through meshes of only 60 mm (selection range 15.3-24.3 cm) and these fish are found mainly in the shallow coastal waters at that time of the year, the Anton Dohrn length curve shows the length composition of approximately the total stock of cod living off Thorvaldsen. The average length was 46.8 cm (Table 6). The broken line in Fig. 3 shows the length composition of cod measured at the same time on board the factory ship. It is obvious, from a comparison of the left sides of the Anton Dohrn curve (solid line) and the factory trawler curve (broken line) with the 110 mm mesh size curve (dotted line), that the ≈80 mm factory trawler net was much less selective than the 110 mm net. The average length of the fish caught by the factory trawler was 48.0 cm, only a little greater than the size of the cod caught by Anton Dohrn. About 38% of the cod caught by the factory trawler (19.8% of the total catch by weight) was too small for the Baader 338 and was processed as fish meal. The average length of the cod going to fish meal was 39.5 cm. This corresponds to an average weight of 500 g per cod. The filleted cod had an average weight of 1,255 g. The proportion of the fish meal cod is, according to the fishmaster on the factory trawler, much higher still, since many of the small cod destined for the Baader 338 are torn when passing through the machine because of their small size. Unfortunately our expert, for lack of time, was not able to give figures on quantity and length composition of this additional industrial cod. According to the statement of the fishmaster off Thorvaldsen 6 baskets of assorted fish meal cod as well as 2 1/2 baskets of cod which did not give useable fillets and likewise went for fish meal. If most of the smaller cod tear in the filleting machine, the proportion of the cod for fish meal is increased by another 12%. This means that, off Thorvaldsen, only 50% of the cod caught were suitable for fillet production!! This is not an extreme maximum figure but confirms the results of calculations of the quantities of landed fish meal and the corresponding reports by the captains on "discards" (thrown overboard) and "industrial cod" (cod processed into fish meal). Also, other methods of calculation used by the Greenland Cod Working Group showed that, in recent years, often more than 40% of the cod caught by trawl off Greenland (especially on board wet fish trawlers) were not used for direct human consumption because fishing was carried out using trawl nets with far too small mesh sizes.

The catches of the factory ship off Thorvaldsen in October 1966 (Table 6) were composed almost exclusively of three year-classes (1963 - 22%, 1962 - 34%, 1961 - 40%). Only 1.7% of the cod were older than 5 years! Only the 5-year-old and the biggest of the 4-year-old cod could be filleted. The efficiency of stock use for this fishery was only 53%! Such a fishery can only be wasteful, uneconomic and short-sighted!!

6. 130 mm mesh size

Whether introduction of a minimum mesh size of 130 mm manila (120 mm nylon) can give a higher and more rational utilization of the cod stock off Greenland is dubious. Even when 130 mm meshes are fully effective (no chafer etc.), the effect is only very small; for the 50% selection point lies at only 42.9 cm, i.e. at this small length and an individual weight of only 625 g (one single fillet weighing 100 g), 50% of the cod of this size are retained in the codend of the net; at a length of 38.4 cm, 25%, and at 47.4 cm, 75%. As Table 1 indicates, the 130 mm selection runs just through the 3-year-old cod. This means that only the 2-year-old, and the 3-year-old, cod of smaller size can escape through the meshes. And it must be emphasized once more that this happens when the 130 mm net is fully effective. The rather low efficiency of a 130 mm mesh size is obvious from Fig. 3 and Table 5. Cod which are caught at a length of 42.9 cm give only an efficiency of stock use of 42%!!

On board factory trawlers, the proportion of the cod for industrial purposes will therefore continue to be high as long as these ships fish on grounds with mainly a young fish population since the range of overlap of sizes of cod for fish meal and for the Baader 338 lies between 43 and 47 cm. In the Holsteinsborg fishery in 1965, if a 130 mm net had been used the amount of fish meal cod would have been reduced from 32% to 20%. Thus 12% of the fish caught with 110 mm mesh size could have escaped. The efficiency of stock use in this fishery would have been increased by 6% to 67%. In the case of the fishery with factory trawlers off Thorvaldsen in October 1966, by using 130 mm nets an efficiency of stock use of 61% instead of 53% would have resulted.

In the fishery for pre-spawning and spawning concentrations 130 mm meshes have no effect because the smallest fish are too big for these meshes. However, the larger meshes guarantee a better flow of water through the codend and there is less piling of water in front of the mouth of the net. This will increase the catchability of the net and thus the catch.

7. Mesh sizes larger than 130 mm

It is well known that no captain, no fisherman, and no fishing industry is interested in a cod fishery off West Greenland where they can only catch small cod of sizes between 25 and 50 cm. All would like to catch cod larger than 50 cm in length. With this in mind and being aware of the very low benefit of an increase in mesh size to 130 mm, the Greenland Cod Working Group was not only proposing to close Great Halibut Bank but to increase the mesh size to at least 150 mm. For 150 mm (manila) the 50% selection point lies at 49.5 cm. This corresponds to a cod weight of 950 g. The efficiency of stock use for this length is 57%. Trawling with codends of 150 mm would mean complete protection of the 2- and 3-year-old cod and furthermore would give a chance of survival to a certain number of the 4-year-old cod at least in the first half of the year.

In the fishery in the growth areas for young fish the introduction of a 150 mm net would mean an essential reduction of "discards" and "industrial fish" because only fish of 40 to 50 cm length would constitute the main part of the catches. Thus not only a large proportion of the fast-growing young cod would remain alive and could grow and produce a greater weight of fish flesh for a higher efficiency of stock use but there would also be a great saving of labour and increase in productivity of the ships from utilization of the larger fish sizes.

For ships without fish meal plants which catch small cod and must discard them there is no economic gain. And because cod thrown back into the sea are dead there is less income in the future for fisherman and fishing companies working off West Greenland.

The following statements can now be made about the previously discussed Holsteinsborg fishery in November 1965 if it were using a 150 mm mesh size of net instead of a 110 mm mesh size of net:

1) the efficiency of stock use will increase from 61% to 76%;
2) the average length of the cod caught will increase from 52.4 cm to 59.8 cm, and the average weight from 1,286 g to 1,782 g with the bigger fish bringing a higher price;
3) the proportion of industrial cod taken by factory trawlers will be reduced from 32% to 7%!
4) 44% of all those cod retained by a 110 mm net can now slip through the meshes of the 150 mm net. They will survive and will improve the weight yield in the future by their rapid growth. If they had been caught by a 110 mm net, 66% (that are the very small cod) of these 44% now surviving would have been turned into fish meal and only the remaining 34% (that are the larger cod) would have been filleted.
5) For the factory trawler fishing with 150 mm mesh size instead of 110 mm these mentioned 34% of small but just filletable cod mean of course a diminution of the quantity of filletable cod. These 34% constitute a reduction of 13.5% by weight of the filletable cod. But this does not mean, however, an identical loss in fillet production of the ship. The reasons are:

   a) the bigger cod produce a higher percentage output of fillets (the filletable cod is on the average 216 g per fish heavier),
   b) there is less tearing and therefore less loss of cod in the filleting machine,

c) there is less loss when dressing the fillets,
d) there is less loss in V-cutting (cutting of boneless fillets).

6) By catching bigger and heavier cod a considerable amount of labour is reduced (economized) and the daily output of the ship is increased.
7) The number of larger cod caught by a 150 mm net is greater than with a 110 mm net.

Unfortunately no exact figures can be given for (6) and (7) above. The losses indicated under (3) and (5) might, to a high degree, be compensated (in weight and money) by the gains mentioned under (2), (6) and (7).

Even if, during the first year after an international adoption of 150 mm mesh size, the fishery in areas with young fish suffers certain economic losses, these are short-term losses and would be out of all proportion to the economic gains resulting from the extremely high growth rate of the West Greenland cod during its juvenile phase of life.

If the same calculations are made for the mentioned winter fishery in the beginning of 1967 in the area of Banan and Fyllas Banks, it becomes obvious that the efficiency of stock use in this fishery increases from 88% to 90% with the adoption of the 150 mm mesh size as 3.3% of the cod would have escaped through the meshes. However, only the smaller cod are lost and the loss in weight is only 1.9%. Nets with bigger meshes giving higher yield practically this calculated loss would be compensated by far by a greater catch. For the Georges Bank haddock fishery it is known that the drastic increase of the mesh size to 114 mm brought about an average increase in catches of up to 10%. First of all a greater number of bigger fish are caught.

If pure shoals of spawners were fished with 150 mm meshes there would be no losses, as all spawning cod are too big even for these meshes. In this case fishing with 150 mm mesh size could only produce a beneficial effect.

## Concluding Considerations

An essential task for the fishery biologist is to cooperate in securing the highest possible long-term use of the fish stocks in the oceans to supply protein to mankind. This requires close cooperation with the fishery. If the practical people in the industry are to understand the arguments of the biologists as to the way in which a certain fishery should be carried out to obtain the highest possible yield and thus the highest earnings (economic output), science must speak a language which is understood by the practical people. This more or less simple method of calculating the efficiency of stock use which has been demonstrated in this study for the first time would seem to contribute to a better understanding,on the part of the fishery people and administrators, of the effect produced by present day fisheries upon the fish stocks.

Having ascertained with the help of the curve for the efficiency of stock use how the cod fishery off West Greenland should be managed, identical studies should now be made for the other important fish stocks of the North Atlantic. In areas where only one fish stock is exploited, it would not be difficult to attain reasonable use by regulation. Difficulties with regard to the realization of appropriate measures of regulation do exist, however, in areas with mixed fisheries. In these areas, certain regulatory measures should be applied so that, in the end, the highest yield by weight (protein for mankind) or/and money is attained. This means that in a fishery for a species of minor importance it must be counted with certain losses. The fishery off West Greenland in the past few years has become almost an exclusive fishery for cod due to the heavy decimation of the redfish shoals, which are only immigrants from the waters to the east of Greenland. It would therefore not be very reasonable or economical to give up the possibility of increasing the yield of the cod fishery because of insignificant losses in the redfish fishery.

Since the existence of redfish in many areas where there are mainly gadoid stocks could become an obstacle to future reasonable measures of regulation for the fast growing gadoids, intensification of the studies of redfish selection in relation to large mesh sizes would seem to be an urgent necessity. Further, these studies should be investigated separately for both the *marinus*-type and *mentella*-type redfish since they show a different behaviour and reaction to trawl nets.

It is understandable that, following an announcement of increase in mesh sizes, fishermen and trawler companies are afraid of losing fish and money, even though there is hardly a captain who does not realize that the present day excessive fishing of young fish stocks is more than unwise when considering the future of the fishery. In order to be able to prove to the industry that, in spite of certain initial losses, a fishery with bigger mesh sizes protects the young fast-growing fish and also produces immediate beneficial effects in respect of catch and financial gain, two questions will soon have to be investigated thoroughly:

1) the effect of different mesh sizes on the flow of water through the net, the pile-up of water in front of the net and the corresponding reactions of the fish;
2) economic studies on board trawlers while at sea, especially on board factory trawlers.

Ad 1: Also no doubts should exist in the industry about a direct connection between the flow of water through the net, on one hand, and the amount of pile-up of water before the opening of the net on the other hand. Better water flow means greater trawling speed. Even the slightest increase in trawling speed results in a larger area being fished and in an increased quantity of water being filtered. An alteration of the mesh size would produce a more decisive effect on the piling up of water in front of the net and, at the same time, upon the behaviour and reaction of the fish. A smaller pile-up of water before the net increases the efficiency of the net for catching bigger fish. This has been demonstrated clearly for the haddock fishery on Georges Bank.

Unfortunately very little is known about these matters. Therefore, there is an urgent need for nets of different materials and mesh sizes to be tested in towing tanks and wind tunnels and for continuous comparative fishing trials on grounds where fish are rather evenly distributed.

Ad 2: More necessary, however, are economic studies at sea especially on board processing ships. Captains report repeatedly on the great variation in daily production due to catching and/or processing small or big fish. As every fish has to be handled several times, the daily production especially on board factory trawlers and salters is essentially dependent on the numbers of fish. To produce 10 t of cod fillets requires 1,100 cod of 70 cm length but 2,800 cod of 50 cm length (at a fillet yield of 35%). For small fish, the fillet yield is smaller, especially when the V-cut is used to produce boneless fillets and for the same production about three times the labour effort is required. In addition, in the case of salting cod, the small salted cod commands a far lower price.

In view of the high cost of labour, especially at sea, a study of the relation between labour and machine costs and the final proceeds, when small cod are processed into fish meal, would be of great interest. For instance, about 10,000 small cod of an average length of 39 cm are required for the production of one single ton of fish meal. On factory ships, salters and wet-fish fishing boats, the catch of small fish always results in an unfavourable relation between labour and other invested costs and the final proceeds. Furthermore, it should be pointed out that, only during periods of favourable catching conditions, are the amounts of daily production also determined to a high degree by the size of the fish caught. And it should also be borne in mind that these unfortunately infrequent times, when the total potential of the labour and the very expensive technical installations of the ship can be fully utilized, are often very important in determining the annual proceeds of the ship and of its owners.

It is certain that studies of rational use of labour on board fishing craft such as are suggested in this paper - and certainly these studies also will have to deal with the problem of how to avoid catching too many small and therefore "labour-intensive" fish - will give interesting results. Surely economic studies can contribute much to the removal of objections within fisheries circles of all ~~profitable measures~~; objections, which still exist today against regulations, which have no other purpose than to guarantee, through the conservation of young fish, the highest possible yields in protein and/or money from the sea and by so doing, guarantee the livelihood of many fishermen and the survival of many renowned fishing companies.

economical systems

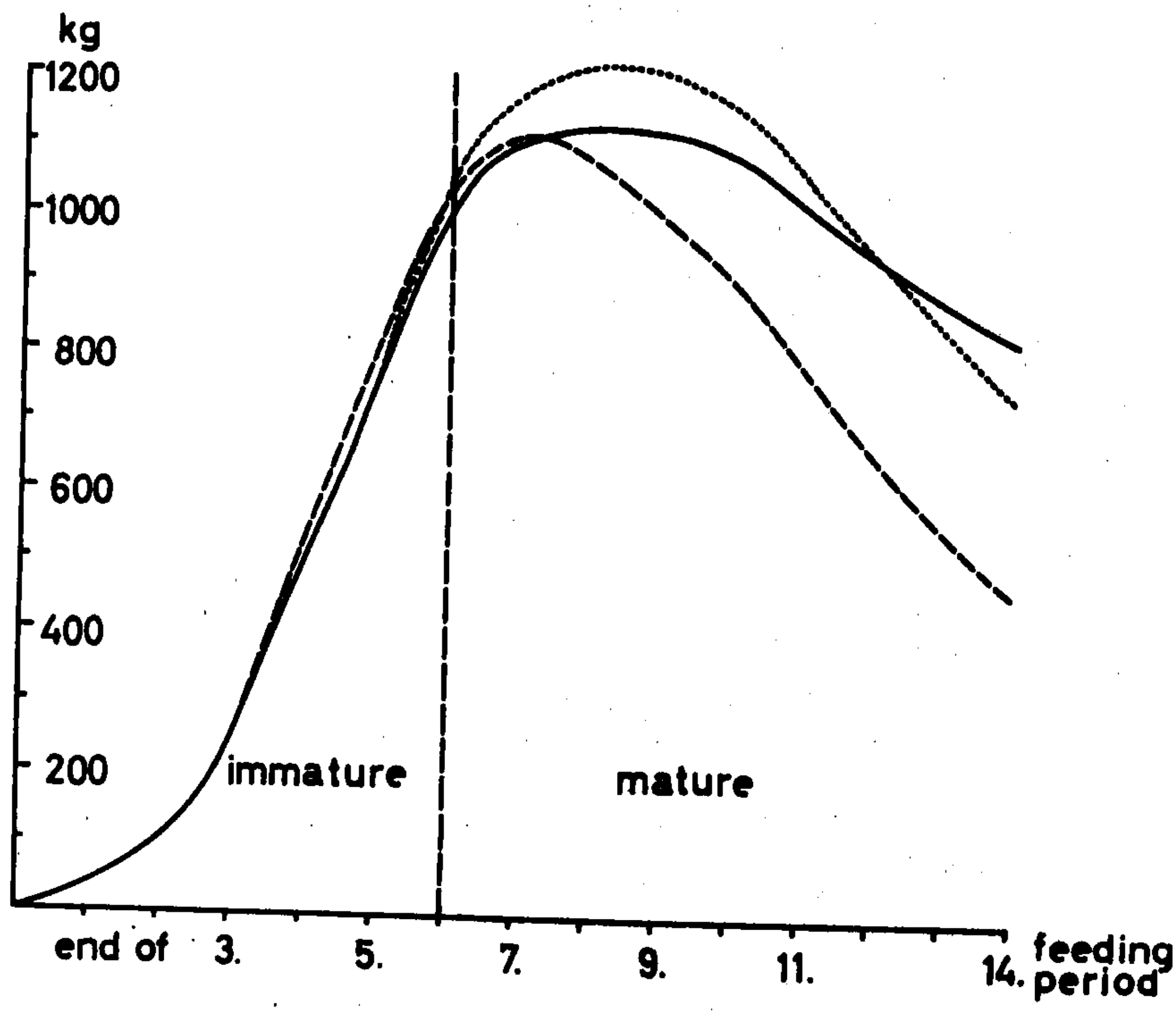


Figure 1

(description in the text)

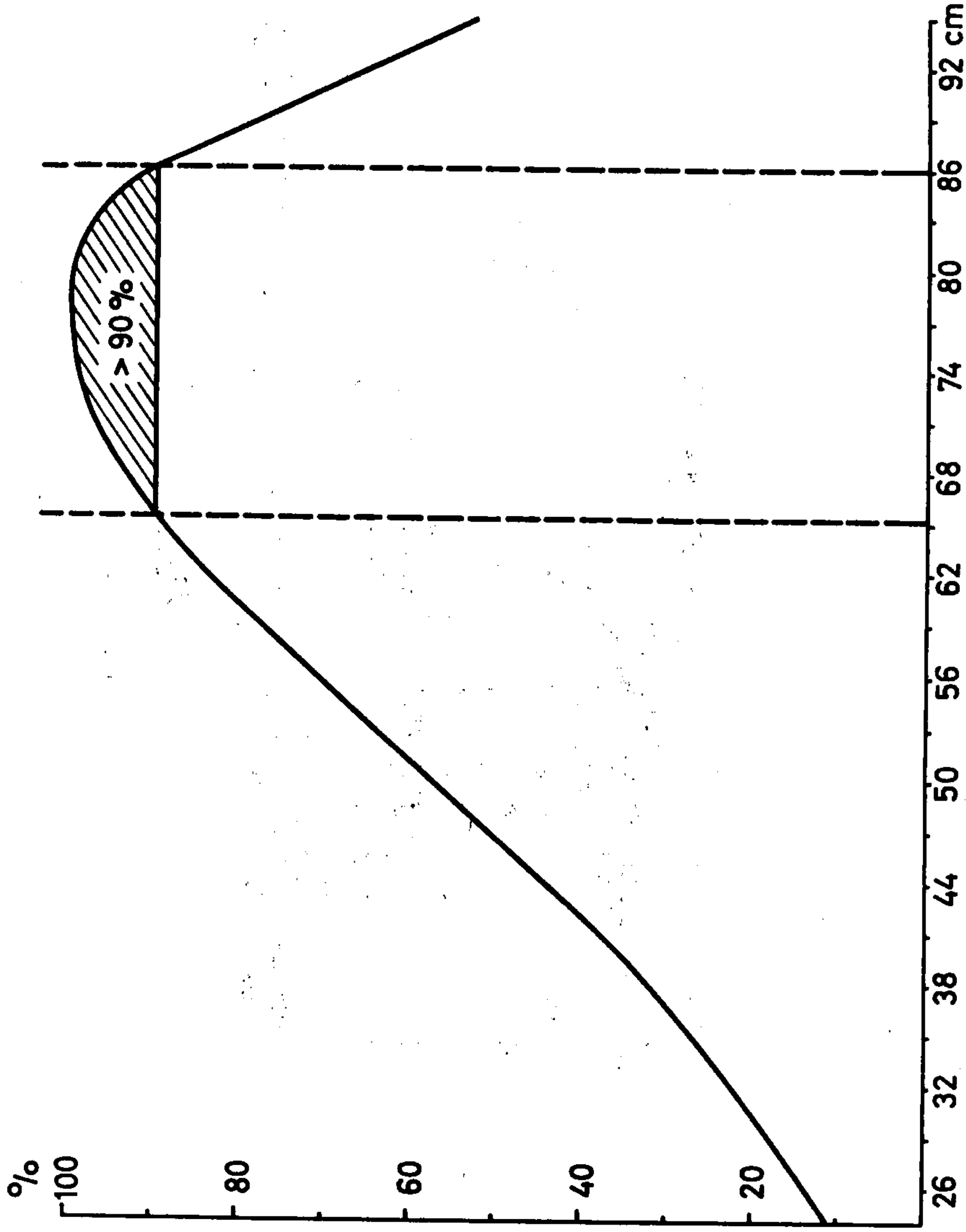


Figure 2 (description in the text)

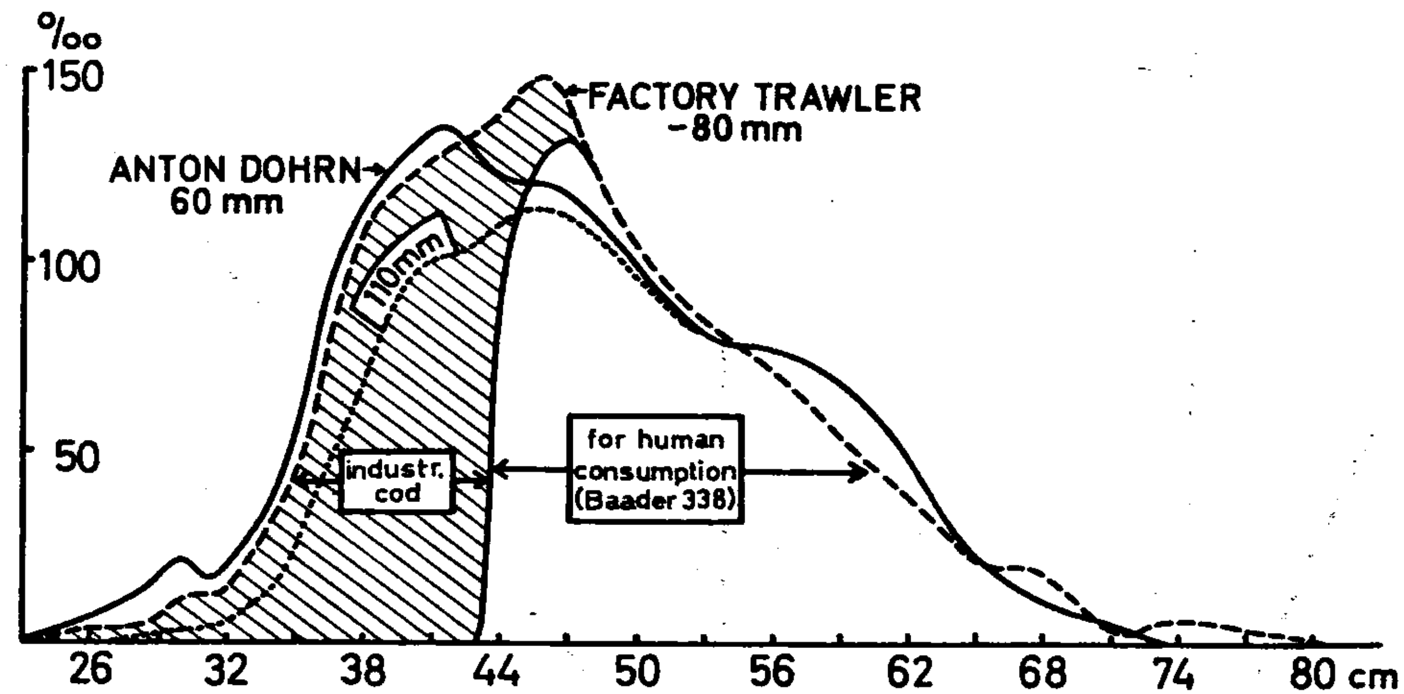


Figure 3

(description in the text)