SIZE SELECTIVITY OF TRAWL GEAR IN ARCTIC SURVEYS

By

William Dickson
Institute of Fishery Technology Research
P.O.Box 1964, N-5024 Bergen, Norway

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CONTENTS

ABSTRACT

In survey work as distinct from commercial there is the extra interest in the younger fish that will soon be entering the fishery. For this reason a shrimp trawl is already used as the standard bottom trawl. A rockhopper groundrope was introduced experimentally to reduce the escapes which occurred between the bobbins of the standard trawl. This markedly improved the proportion of smaller cod in the catches, and improved the sampling for haddock also. Additionally, experiments were conducted with different sweep lengths, twice and half the 40 m used on the standard rig, again leading to changes in the length frequency distribution of the catches, more bigger fish and fewer smaller ones with increasing sweep length. So far the statements are in relative terms. To turn the results into actual bias or raising factors which can be used to come much closer to the true length frequency distribution, necessarily requires a real estimate of gear efficiency or effective spread by species and length group. The paper fits the results from many comparisons into a theoretical framework to reach conclusions about gear efficiency.

Two appendices are added, which deal with other survey trawls used by people who co-operate with us in surveys and/or in common studies. The first deals with trying to estimate the escapes through the forward meshes of a trawl on a length distribution basis. The second deals with comparing with our own the probable efficiencies of survey trawls used by Canadian and Russian colleagues.

Introduction

It is well known that every kind of fishing gear gives a biassed sample, both as to species and to length distribution. Of particular concern in Arctic surveys has been the undersampling of small cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.) by bottom trawl. It was also becoming apparent that the use of different sweep lengths was probably affecting the bias of the samples. Already a shrimp trawl was used as the standard bottom trawl, so as to avoid escapes through the meshes of the forward part of the trawl. A rockhopper groundrope was introduced experimentally to cut down on escapes which occurred between the bobbins, and experiments were conducted with different sweep lengths twice and half the length of the 40 m sweeps used on the standard sampling rig. However, catch ratios established by comparative fishing remain merely relative unless or until some measure of the effective spread of at least one of the gears is established.

Progress had already been made in this direction by colleagues, which for a start enabled the net efficiency to be estimated by size groups, this being a good step toward the efficiency and size selectivity of the whole gear. The results from the considerable amount of comparative fishing data also have to fit into the theoretical framework that is developed here.

Materials and methods

The materials and methods are the same as reported by Engås and Godø (1989) in their experiments with bag nets under the fishing line, and in their comparison of length compositions with different length sweeps (1989). The data for rockhopper and bobbin gear comparisons is as reported by Engås, Jacobsen and Soldal (1988), plus a few more comparative hauls made earlier.

Effectiveness and efficiency, definitions

Efficiency must be a simple ratio catch/encounters. Effectiveness includes efficiency, but also includes gear size, speed and its headline reach into the vertical distribution profile. Effectiveness considers the whole water column, and is derived from the equation C = qEN, where C is catch, q is effectiveness, E is effort, and N local abundance. This gives q in units of m^2/s, or the area of sea that is effectively cleared of fish per unit time. Effectiveness may also be called catchability (catching ability), but not catchability coefficient.

It is possible that ship noise, ship lights or the warps may disturb the natural vertical profile as shown in Figure 1. If so, it is the vertical profile occuring at the gear which has to be used. There is also the possibility of a horizontal availability coefficient F_{H3} if the ship disturbs the fish in a lateral direction.

$$Number\ of\ encounters = Y_b \cdot V \cdot t \cdot N \cdot F_{V3} \cdot F_{H3}$$

where Y_b = otterboard spread, V = speed, t = time, N abundance (fish/unit area), and F_{V3} is the vertical availability at the gear.

Also

$$Effective\ spread\ Y_e = Y_b \cdot Efficiency$$

$$Catch = Y_b \cdot V \cdot t \cdot N \cdot F_{V3} \cdot F_{H3} \cdot Efficiency$$

This is not to say that Efficiency is independant of speed, any more than Y_b and F_{V3} are independant of speed. Since Catch = qEN and Effort E = t, it follows that

$$Effectiveness = Y_b \cdot V \cdot F_{V3} \cdot F_{H3} \cdot Efficiency\ (units\ m^2/s)$$

Normally, when comparing catch rates, it is the catchabilities that are being compared. It follows, however, that for nets of equal headline height, equal spread, towed close together at the same speed and for the same time, then as much as possible has been done to eliminate the effects of V, t, F_{V3} and F_{H3}, so that catch ratios are efficiency ratios or ratios of effective spread.

Analysis of results

Net efficiency, bobbins and rockhoppers

The escape of fish under the fishing line of this same sampling trawl was discussed by Engås and Godø (ibid.). They extrapolated the results of what was caught in bags under the fishing line to what would escape over the whole bobbin groundrope. On this particular net the lower wings are cut away so that the groundrope spread is considerably less than the headline spread. For the purpose of this paper, headline spread and net spread are taken as the same. Bag catches may as well be extrapolated to the whole width of the trawl net (Y_n). They also gave what was caught by the bobbin rigged trawl for the same series of hauls. The bobbin trawl net efficiency f_{nb} may be described as:

$$f_{nb} = catch/(catch + escapes) \text{ or } catch/encounters$$

The bags would not be able to measure all kinds of escapes viz:

A very few fish pass between the wing ends, re-cross this line, and swim out.

More seriously some of the bigger fish (mostly cod) will remain swimming in front of the ground rope when the gear is hauled.

Some fish (mostly bigger haddock) swim up and over the headline.

Escape of those fish remaining in front of the groundrope can be allowed for by using the diagram of Blaxter (1969). The values used here are that in Arctic waters the cod can achieve 400 m at 1.9 body length/s and 100 m at 2.8 body lengths/s. The distance that can be swum at a towing speed of 1.5 m/s is then interpolated by length group and taken as a proportion of the half hours towing distance. The net efficiency is then reduced by this amount.

Using the bobbin spread of 11.5 m, extrapolating losses to 19.5 m net spread, and introducing the correction factor for cod remaining in front of the groundrope, gives net efficiency estimates as in Table 1.

In a similar way the net efficiency of the rockhopper gear may be estimated because effectively, the escapes over the 11.5 m width of the bobbins should now be transferred to the catch, while the escapes at the ground between groundrope spread and net spread remain. Thus arises the rockhopper net efficiency f_{nrh} in Table 1.

The real values of f_{nb} and f_{nrh} should begin to fall again because of those remaining in front of the groundrope. Figure 2 shows the calculated trend. In this case, the catch ratio is the same as the effective spread ratio Y_{eb}/Y_{erh}, this and f_{nb}/f_{nrh} are given in Figure 3. The plots of Y_{eb}/Y_{erh} are made on considerably more data (about 13 000 cod) than f_{nb}/f_{nrh} from the bag experiments (about 1100 cod). The general agreement between the two plots is encouraging, in that with the same length of sweeps there ought to be near agreement.

Without as yet considering the effect of otterboards, the effective spread may be considered as:

$$\textit{Effective spread} = \textit{net efficiency (net spread} + \textit{sweep efficiency} \cdot \textit{sweep spread)}$$

For the moment sweep efficiency covers all that happens in the sweep path without considering whether due to sweeps, sand clouds or otterboards. Effective spread Y_e may be thought of as being established when the gains from pathwidth Y_b - Y_e equal the losses between Y_e and the codend.

The catch rate relationship between the two gears may thus be expressed at its simplest as:

$$\begin{aligned} Y_{eb}/Y_{erh} &= f_{nb}(Y_{nb} + f_{sb} + (Y_{bb} - Y_{nb}))/f_{nrh}(Y_{nrh} + f_{srh}(Y_{brh} - Y_{nrh})) \\ &= f_{nb}/f_{nrh} \cdot (19.5 + f_{sb} \cdot 42.5)/(18 + f_{srh} \cdot 35) \end{aligned}$$

The rockhopper gear has a little less otterboard spread, $Y_{bth} = 53$ m, $Y_{bb} = 62$ m, and less net spread, $Y_{nth} = 18$ m, $Y_{nb} = 19.5$ m, because of the greater drag of the rockhoppers, weighing 300 kg in water, the bobbin groundrope 180 kg.

Constraints

Since f_{nb} is a substantial proportion of unity for cod > 40 cm, it must follow that the sweep efficiency is also a sizeable proportion of unity, for if it were small, the sizeable increase of catch associated with longer sweeps would not be attainable. A good starting point for the consideration of this overall sweep efficiency is whether it is upwards or downwards of 0.5.

There are certain constraints on the values of f_n, Y_e, and f_s. At the lower end of the fish size range values will tend to zero. Net efficiency and effective spread should have a decreasing slope with increase of length, and may eventually have a negative slope if the fish grow that big. The slope of the sweep efficiency should likewise decrease gradually, but there is no apparent reason for it to have a negative slope at the top end. The maximum value of Y_e can hardly be > Y_b, and if it is < Y_n for commercial fish, one can suspect gear defects. None of the efficiencies should be > 1. Discontinuities in the changes of slope are hardly likely. Another constraint is that values for f_n, Y_e and f_s, established for the 40 m sweep bobbin gear, must be taken as the same for all comparisons, i.e. versus the 40 m sweep rockhopper gear, versus the 80 m sweep bobbin gear, and versus the 20 m sweep bobbin gear.

Allowing for otterboard effects

Otterboards are big enough to have an important effect on fish herding or avoidance, but whether beneficial or otherwise was never clear. When it came to analysing results of comparative fishing experiments with long, average, and short sweeps, the short sweep case indicated that any large negative effect of otterboards was improbable, at least as long as they were > 40 m apart. Negative effect is severe because fish are removed from the system. The positive effect is weaker because fish are not added to the system, only redistributed within it somewhat more favourably. Analyses along these lines suggested both positive and negative effects as likely (Figure 4).

The waterflow from the otterboard flows over the top and round the back of it. Fish immediately on the inside of the board can be sucked out. Others could follow them. The sand cloud at this point is low down, and the area immediately behind the otterboard and over the low sand cloud may present itself as an escape route, particularly for fish which are above otterboard height, but still below headline height. Other fish farther away react positively being herded toward the centre and turning toward the net as the otterboard passes them. The splitting line, it is suggested, is not immediately in front of the otterboards, but some very few metre inside them. Inside the splitting line the effect is positive, outside of it negative. The warp may also have some negative effect immediately in front of the otterboard. Occassionally fish are seen escaping over the otterboard, more commonly few or no fish are seen near the otterboard. The positive effect acts over a wider area.

Proceeding to introduce this concept into the equations, let the positive effect be acting over a pathwidth R_{bi} (both boards, R_{bi} = board paths inward) and herding inwards from the splitting line. Let the negative effect be acting over a pathwidth R_{bo} (both boards, R_{bo} = board paths outwards) and removing fish from the system. Because of the negative effect, the amount of fish available to the gear is reduced so that without positive effect the equation becomes

$$Y_e = f_n(Y_n + f_s(Y_b - Y_n - R_{bo}))$$

Because of the positive effect, the density of fish toward the centre is increased in the proportion $(Y_b - R_{bo})/(Y_b - R_{bo} - R_{bi})$, and the remaining path over which the sweeps and sand clouds herd fish, is $(Y_b - Y_n - R_{bo} - R_bi)$. The equation thus becomes:

$$Y_e = f_n(Y_n + f_s(Y_b - Y_n - R_{bo} - R_{bi}))(Y_b - R_{bo})/(Y_b - R_{bo} - R_{bi})$$

Some preliminary calculations suggested that R_{bi} = 10 m and R_{bo} = 5 m would be suitable values. This means that the splitting line is 2.5 m inside each board, and what is inside the splitting line for a distance of 5 m is all herded toward the centre, being then more or less evenly distributed within the remaining pathwidth. Later it was decided that since the energy budget for small fish limits their reaction to more distant events, it would be more realistic to set R_{bi} at a range of values dependant on fish size. Doing this does not affect Y_e, f_n or the overall efficiency f. It only affects the estimated sweep efficiency. Raising R_{bi} has the same effect as raising the sweep efficiency near the door end of the sweep to 1.0, and therefore lowers the remaining sweep efficiency. Using equations modified for otterboard effect, Table 2 emerges as does Figure 5.

The calculation method is that values are displayed on a personal computer spread sheet in a form similar to that in Table 2. Values of f_{nb}, f_{nrh}, Y_{eb}/Y_{erh}, R_{bot} and R_{bi} are fixed. Put in any values for Y_{eb}, and all the remaining values emerge. Observing the constraints quickly settles the values of Y_{eb} that have to be entered.

For instance, replacing the maximum value of Y_{eb} = 25 m in Table 2 with a value of 27 m forces the rockhopper sweep efficiency f_{srh} to > 1, and also forces f_{s80} in Table 3 to very nearly 1. Similarly, lowering Y_{e40} to 22.5 leads to difficulties with Table 4. Raising R_{bo} > 5 m creates problems with calculated sweep efficiency, but it might well be < 5 m. Raising R_{bi} to a range of 5, 7, 9, 11, 13, 15, 17 in Table 2, leads to an improbable downturn in sweep efficiency f_{sb}.

Effects of long and short sweeps

All the comparisons between long, medium, and short sweeps, were made with the gear rigged with bobbins. The 80 m sweep case introduces a 40 m single sweep between 40 m spreading wires and backstrops (10 m). The short sweep gear had the spreading wires attached to top and bottom of the otterboards in order to keep the headline height substantially the same as in the other two cases. It also had compensating weight added to the lower sweeps to keep sweep weight the same as the 40 m sweeps. Otterboard spreads Y_b and net spreads Y_n are taken from acoustic transponder equipment with information relayed acoustically back to the ship. It will be noticed that the spreads change a little from one set of experiments to another. This is because the experiments were done at various times and places, the 80 m/40 m comparison being in fact collected over several years.

80 m/40 m comparison

The totals of cod in this comparison approached 10,000 individuals. The catch ratio at each length group and the smoothing used are given in Figure 6. The values of net efficiency are not expected to be very different whether the sweeps are long or short. Net efficiency for the longer sweeps is here given a 5% advantage because with the extra sweep weight the net should bite the ground better. Sweep efficiency for the 40 m sweep rig is maintained the same as for the bobbin gear in the rockhopper comparison. Thus with some balancing between the various constraints, Table 3 arises.

The plots of Table 3 are given in Figure 7. It would appear that the sweep efficiency for the 80 m sweeps is very low for small cod. The sand clouds as seen on the rotating sector scanner are well outside the wing end with the 80 m sweep rig, and small cod passing over or under the sweeps near the net seem the likely route of their escape. The dramatic increase in sweep efficiency for the bigger cod may suggest that the strength of the reaction is related to the amount of fish that the extra spread makes available.

40 m/20 m comparison

Here the otterboard spread ratio was 63.5 m/39.5 m or 1.61, while the catch ratio for all sizes was only 1.26. Such results are not easily explainable, except by the otterboard effect or a very high sweep efficiency with the lower sweep close to ground in the short sweep case. The sweep path of the 20 m sweep gear is much more overlapped by the otterboard effect, so that the overall efficiency of the 20 m sweep gear is good (Table 4 and Figure 8). By day the catch ratio was only 1.1 and by night 1.36, suggesting that the magnitude of R_{bl} may well be affected by visibility .

Haddock

The same procedures were followed for haddock. They are given only 80% of the swimming speed of cod of the same length to stay ahead of the trawl for a given distance.

Figure 9, showing the bobbin and rockhopper net efficiencies, sets the pattern for the other comparisons. The slopes of the net efficiencies rise much more steeply than for cod, flatten off and then tend to fall gradually. The catch ratios are also compared with the net efficiency ratios in Figure 9. Table 5 and Figure 10 deal with the rest of the bobbin/ rockhopper comparison. Satisfying the constraints requires that the effective spread for haddock be rather greater than for cod.

The same loss of small haddock with long sweeps occurs. Details of the 80 m/40 m comparison are given in Figure 11.

Haddock did not seem to be quite so well herded as cod by the short (20 m) sweep gear, although they were not herded badly, the overall catch ratio for all sizes being the same as the otterboard spread ratio.

Discussion

The general conclusions about the performance of the bobbin, rockhopper, 40 m, 80 m, and 20 m sweeps have been discussed already by Engås and Godø (ibid.). Linking all the results in an interdependant model has something of the benefits of a navigation system. It does not prove where one is, but it narrows the possibilities of where one could be. The model is fairly crude, but the quantitative data to be fitted into it is fairly simple too. As yet the model is a composite of day and night results, mainly because the original bag experiments were not extensive enough to be so differentiated. To differentiate net efficiency, effective spread and sweep efficiency by visibility, conditions is a necessary objective, similarly to differentiate quantitatively between sweep and sandcloud effects.

The most serious observed, but unquantified, loss of efficiency is avoidance by big haddock rising to swim over the headline in good visibility. When both wings of the net, and even more so with no sweeps, when both otterboards also are in view, are cases which require more refined modeling for species which tend to rise. There is a clear difference between the good overall efficiency of the short 20 m sweep case here and the very poor efficiency no sweep case reported by Bagenal (1958).

The most disturbing feature of the interdependant results is the rather high value of derived sweep efficiency for the rockhopper gear at the upper length groups for both cod and haddock (Figures 5c and 10 c). If this is not correct, it most likely arises from the fact that in the original bag catches, there were relatively few cod > 50 cm or haddock > 40 cm, whereas the comparative fishing catch ratios were based on many more fish.

Indices of abundance for arctic surveys are computed, assuming the bobbin trawl has an effective path width of 25 m for the whole length range for both species. Tables 2 and 5 indicate that this is a fairly reasonable value to use for cod > 50 cm and haddock > 30 cm. The best effective spreads that can be given by length group for Y_{eb} (bobbins) and Y_{erh} (rockhoppers) in these same tables are now summarised as:

Effective spread cod	10/19	20/29	30/39	40/49	50/59	60/69	70/79	cm
Bobbins	3.5	8	13	18	22	25	22	m
Rockhoppers	19	23	26	30	33	35	33	m

Effective spread haddock	10/19	20/29	30/39	40/49	50/59	cm
Bobbins	3	17	27	30	23	m
Rockhoppers	16	24	30	37	38	m

Because of escapes by big haddock over the headline, the effective spread for haddock may be rather lower at the top end than found here.

The above summary of effective spread values is derived from data collected over several years at different seasons and places, by day and by night. It is therefore thought to be generally useful for survey purposes, though somewhat lacking in precision for any particular situation. Checking from past data that the "improved" length/frequency distributions given by the different gears is approximately the same for different situations, is really only the reverse process of deriving the effective spreads; it is a useful check, but no proof. A useful test would be to use the raising factors on new length/frequency data from the two trawl rigs to find how closely the two "improved" length/frequency distributions agree. The raising factor for 20-29 cm cod caught by the sampling trawl with 40 m sweeps and bobbin groundrope is 25/8, and for rockhoppers 35/23, to give the "improved" % length/frequency distributions from the raw data sampled from the catches of the two gears.

Conclusions

1. From a series of independent experiments, it has been possible to synthesise a more general, interdependent theory, relating net efficiency, sweep efficiency, otterboard effect, and effective trawl spread.

2. Values of effective spread by size group are obtained, and these can be used to improve on estimates of abundance and of the length/frequency distribution of the cod and haddock taken by the sampling trawl.

3. The emphasis in this paper has been on adequately sampling fish at the lower end of the length/frequency distribution range for scientific purposes. By the same tokens how to avoid taking them for conservation reasons may be inferred.

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Table 1. Estimates of net efficiencies from bag experiments and including a correction for cod remaining in front of the groundrope when when hauling, their ratios and catch ratios.

Length (cm)	f_{nb}	f_{nb} corrected	f_{nsh}	f_{nsh} corrected	f_{nb}/f_{nsh} corrected	y_{eb}/y_{esh} catch ratio
5-9	0.09	0.09	0.62	0.62	0.15	-
10-14	0.10	0.10	0.68	0.68	0.15	0.04
15-19	0.10	0.10	0.63	0.63	0.16	0.05
20-24	0.20	0.20	0.67	0.67	0.30	0.27
25-29	0.24	0.24	0.69	0.69	0.35	0.42
30-34	0.23	0.23	0.68	0.68	0.34	0.41
35-39	0.34	0.34	0.73	0.73	0.47	0.51
40-44	0.48	0.48	0.78	0.78	0.61	0.62
45-49	0.37	0.36	0.74	0.73	0.49	0.62
50-54	0.58	0.56	0.83	0.82	0.69	0.65
55-59	0.54	0.51	0.81	0.78	0.65	0.75
60+	0.70	0.62	0.88	0.80	0.78	0.63

Table 2. Smoothed values of net efficiency and effective spread ratios with resulting values of sweep efficiency, effective spread and overall efficiency.

Sizegroup (extrapolated)	10/19	20/29	30/39	40/49	50/59	60/69	70/79 cm	
R_{bi}	5	6	7	8	9	10	11	m
f_{nb}	0.10	0.21	0.32	0.44	0.54	0.60	0.53	
f_{nsh}	0.61	0.67	0.71	0.75	0.79	0.80	0.73	
y_{eb}/y_{esh}	0.18	0.35	0.50	0.60	0.68	0.70	0.67	
F_{sb}	0.38	0.46	0.53	0.53	0.53	0.53	0.52	
f_{ssh}	0.38	0.49	0.57	0.69	0.75	0.83	0.88	
Y_{eb}	3.5	8	13	18	22	25	22	m
Y_{esh}	19	23	26	30	33	35	33	m
f_b	0.06	0.13	0.21	0.29	0.36	0.40	0.36	
f_{sh}	0.36	0.43	0.49	0.57	0.62	0.66	0.62	

Input dimensions			
	Y_{nb} 19.5 m	Y_{bb} 62 m	R_{bo} 5 m
	Y_{nsh} 18.5 m	Y_{bsh} 53 m	R_{bi} as above

Table 3. Effective spreads, net, sweep and overall efficiencies for the 80 m and 40 m sweep rigs.

Size group	7/16	17/26	27/36	37/46	47/56	57/66	67+ cm
R_{bi}	5	6	7	8	9	10	11 m
$f_{n4}0$	0.08	0.17	0.29	0.41	0.52	0.60	0.58
f_{n80}	0.05	0.14	0.30	0.43	0.55	0.63	0.61
y_{e80}/y_{e40}	0.36	0.76	1.05	1.35	1.52	1.58	1.57
f_{s40}	0.39	0.45	0.52	0.54	0.53	0.52	0.51
f_{s80}	0.0	0.25	0.3	0.57	0.69	0.74	0.73
y_{e40}	2.7	6.1	11.1	16.0	20.3	23.4	22.6 m
y_{e80}	1.0	4.7	11.7	21.6	30.9	37.0	35.5 m
f_{40}	0.05	0.11	0.19	0.28	0.35	0.40	0.39
f_{80}	0.01	0.06	0.16	0.28	0.40	0.48	0.46

Input dimensions Y_{n40} 19.5 m Y_{b40} 57.8 m R_{bo} 5 m
Y_{n80} 19.1 m Y_{b80} 76.5 m R_{bi} as above

Table 4. Effective spreads, net, sweep and overall efficiencies for the 40 m and 20 m sweep rigs.

Sizegroup	17/26	27/36	37/46	47/56	57/66	67+ cm
R_{bi}	6	7	8	9	10	11 m
f_{n40}	0.17	0.29	0.41	0.52	0.60	0.58
f_{n20}	0.17	0.29	0.42	0.52	0.60	0.58
Y_{e40}/Y_{e20}	1.39	1.15	1.34	1.12	1.07	1.22
	1.19	1.24	1.26	1.26	1.26	1.26 *
f_{s40}	0.46	0.52	0.53	0.52	0.52	0.51
f_{s20}	0.78	0.88	0.86	0.81	0.79	0.76 **
y_{e40}	6.6	12.0	17.2	21.8	25.2	24.4 m
y_{e20}	5.5	9.7	13.7	17.3	20.0	19.4 m
f_{40}	0.10	0.19	0.27	0.34	0.40	0.38
f_{20}	0.14	0.25	0.35	0.44	0.51	0.47

* smoothed
** not critical because sweep path is narrow

Input dimensions Y_{n40} 20 m Y_{b40} 63.5 m R_{bo} 5 m
Y_{n20} 20.5 m Y_{b20} 39.5 m R_{bi} as above

Table 5. **Haddock, smoothed values of net efficiency and effective spread ratios with resulting values of sweep efficiency, effective spread and overall efficiency.**

Sizegroup	10/19	20/29	30/39	40/49	50+ cm
R_{bi}	5	6	7	8	9 m
f_{nb}	0.12	0.53	0.75	0.80	0.61
f_{nch}	0.61	0.79	0.90	0.92	0.90
Y_{eb}/Y_{ech}	0.2	0.7	0.9	0.81	0.6
f_{sb}	0.15	0.29	0.40	0.43	0.43
f_{sch}	0.18	0.36	0.54	0.69	0.78
Y_{eb}	3.2	17	27	30	23 m
Y_{ech}	15.6	24.3	30	37	38.3 m
f_b	0.05	0.27	0.44	0.48	0.37
f_{ch}	0.29	0.46	0.57	0.70	0.72

Input dimensions	Y_{nb} 19.5	Y_{bb} 62	R_{bo} 5
	Y_{nch} 18.5	Y_{bch} 53	R_{bi} as above

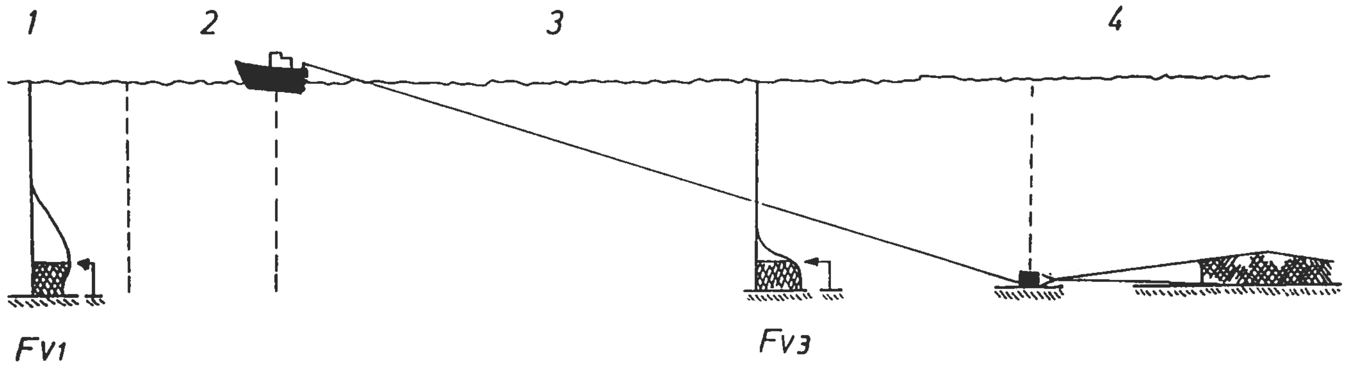


Figure 1. The undisturbed vertical profile of fish abundance is as in zone 1. Before the arrival of the ship there is the possibility that the vertical profile is disturbed in zone 2. Between the ship and the gear in zone 3 there is farther possibility that the fish are driven down by vessel noise, by vessel lights, by the warps, so that the vertical profile becomes as shown. It is the vertical availability coefficient F_{V3} at the otterboards that determines the number of encounters with the gear. In zone 4 there is herding and avoidance. The same 4 zones may be used to consider possible lateral disturbances.

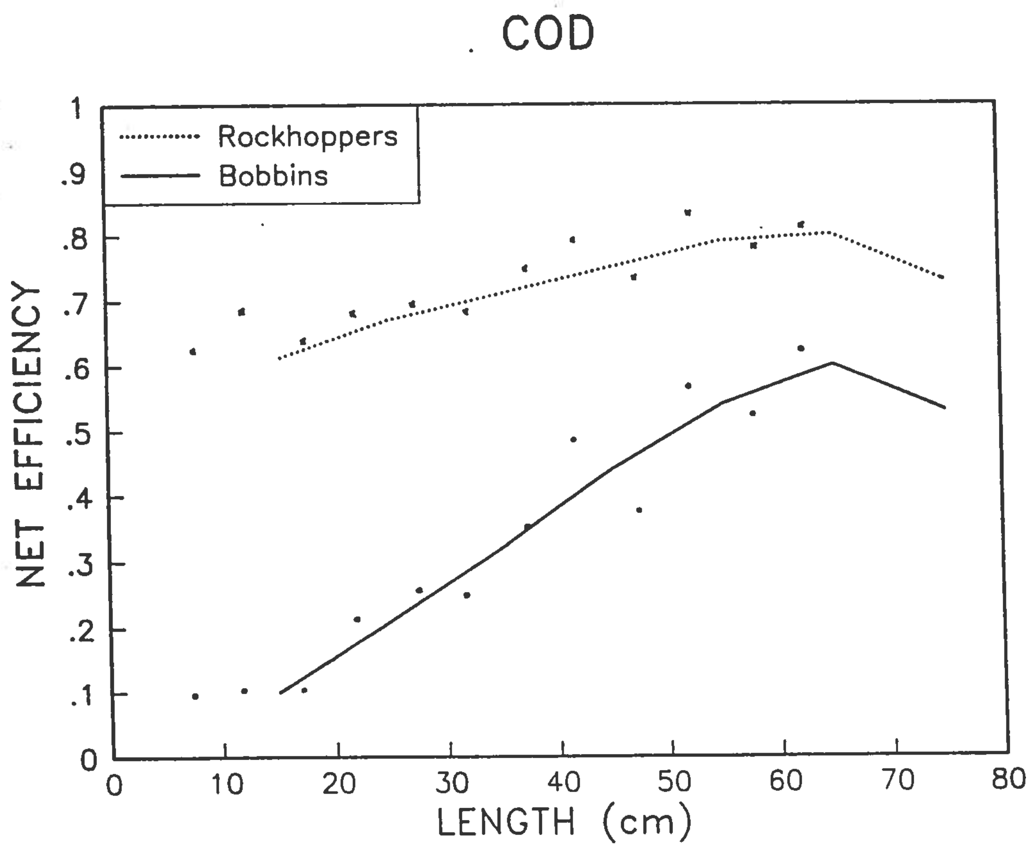


Figure 2. Net efficiencies, plots derived from bag experiments with correction for cod remaining in front of groundrope when the trawl is hauled.

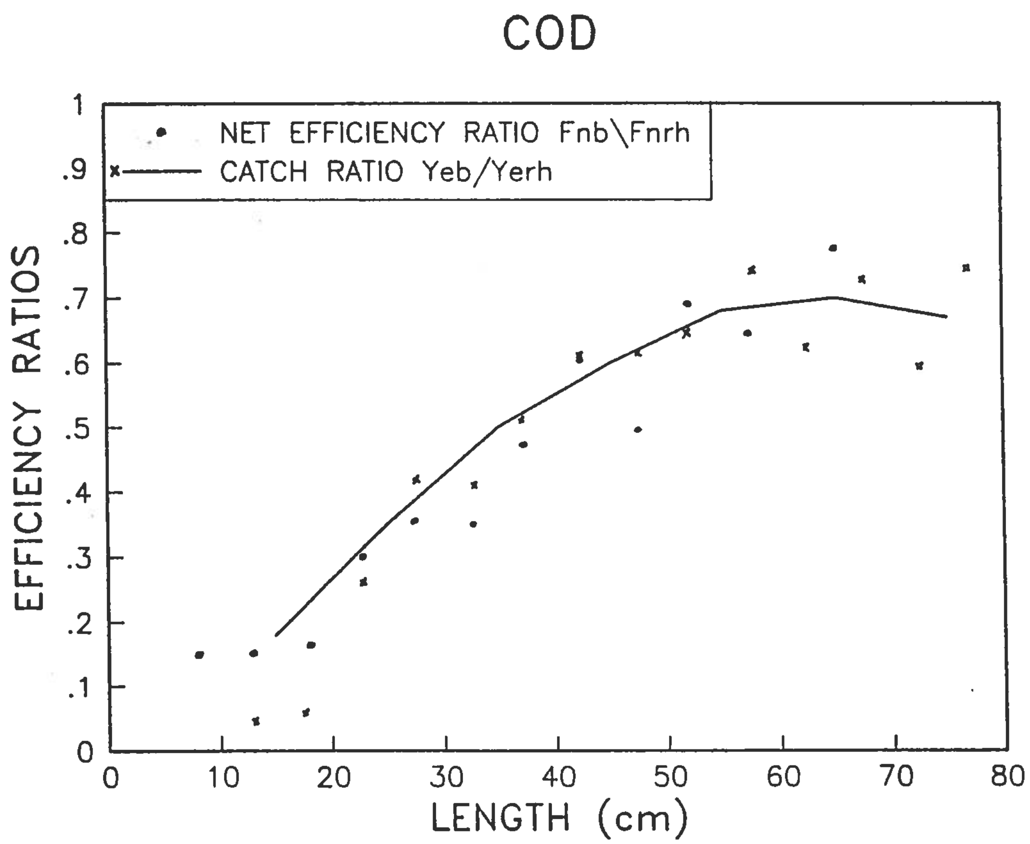


Figure 3. Ratio of net efficiency bobbins to rockhoppers also the ratio of effective spreads (catch ratio). They are in fair agreement.

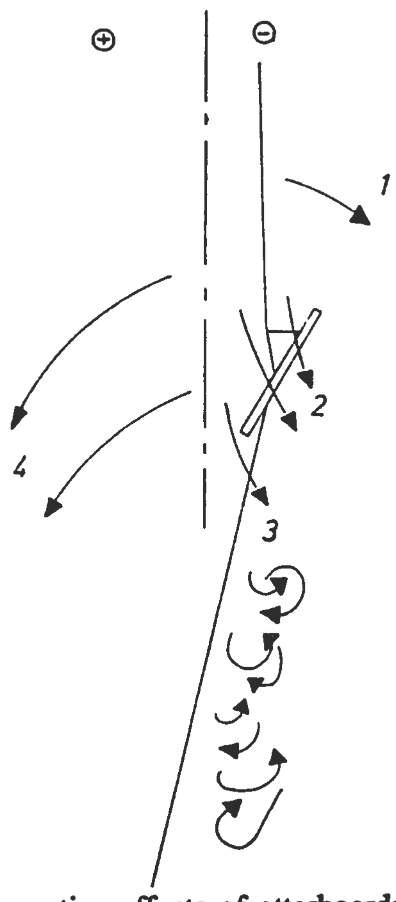


Figure 4. Positive and negative effects of otterboards, positive inside the splitting line, negative outside it. The positive effect causes more favourable redistribution, the negative effect causes system losses, 1 - escape from warp approach, 2 - escape with waterflow over the top of otterboard, 3 - escape with waterflow round the back of the otterboard and over the still low sand cloud, 4 - beneficial herding.

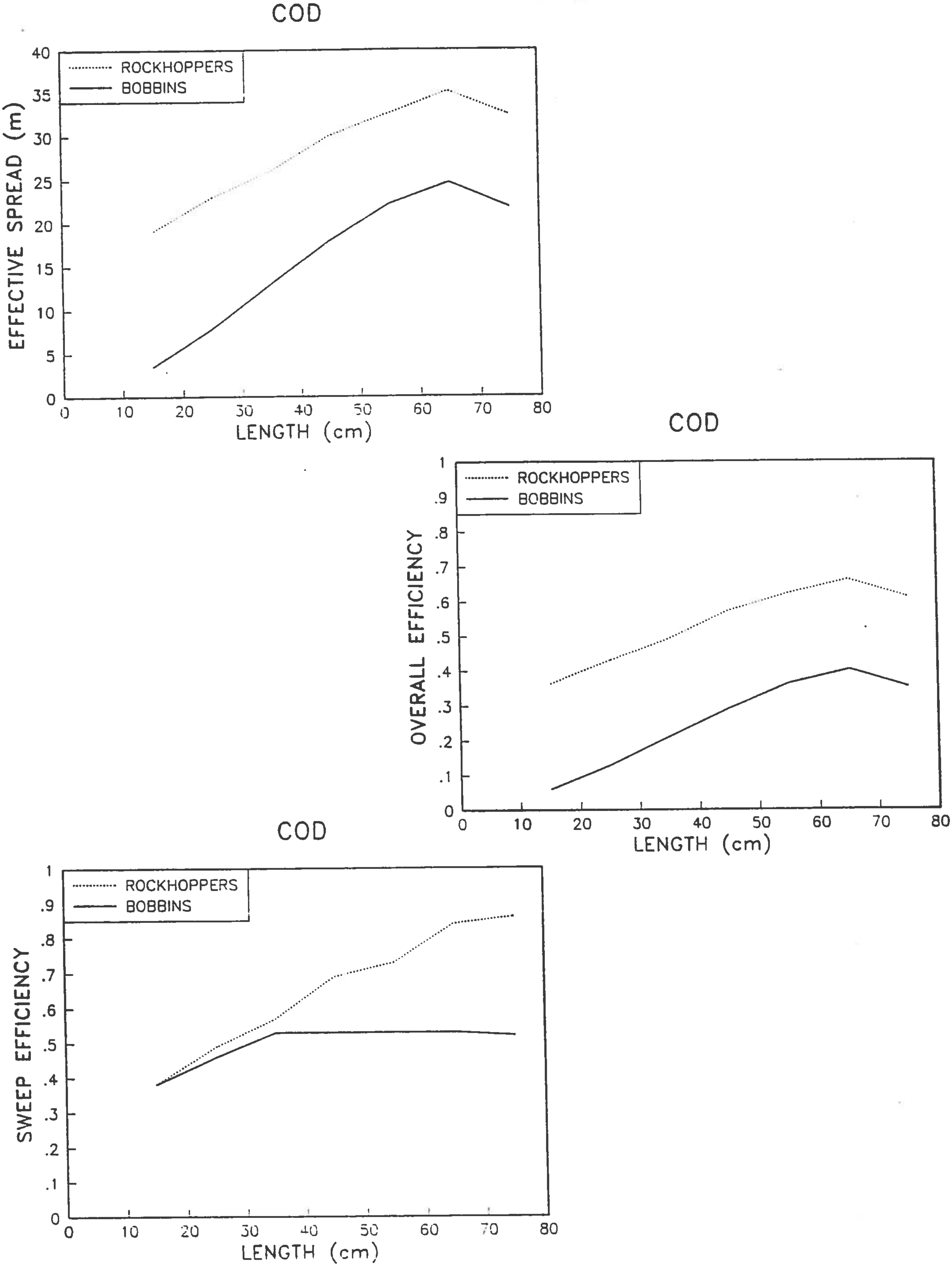


Figure 5. a) Effective spread.
b) Overall efficiency (effective spread/otterboard spread).
c) Sweep efficiency.
For cod, both gears with 40 m sweeps.

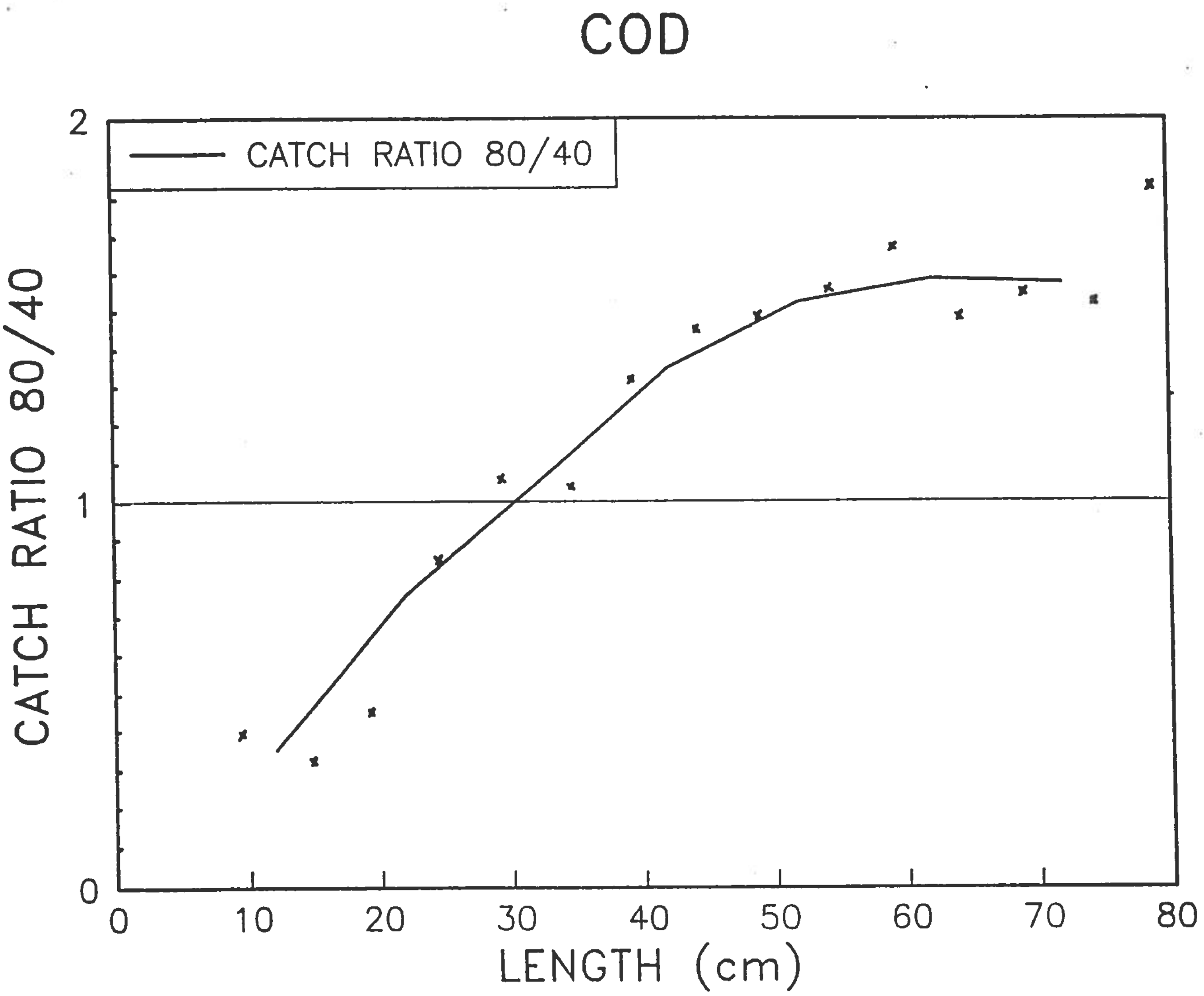


Figure 6. **Catch ratio 80 m/40 m sweeps by 5 cm length groups and smoothing used for 10 cm length groups. Total numbers of cod 9330, but few fish below 21 cm or above 76 cm.**

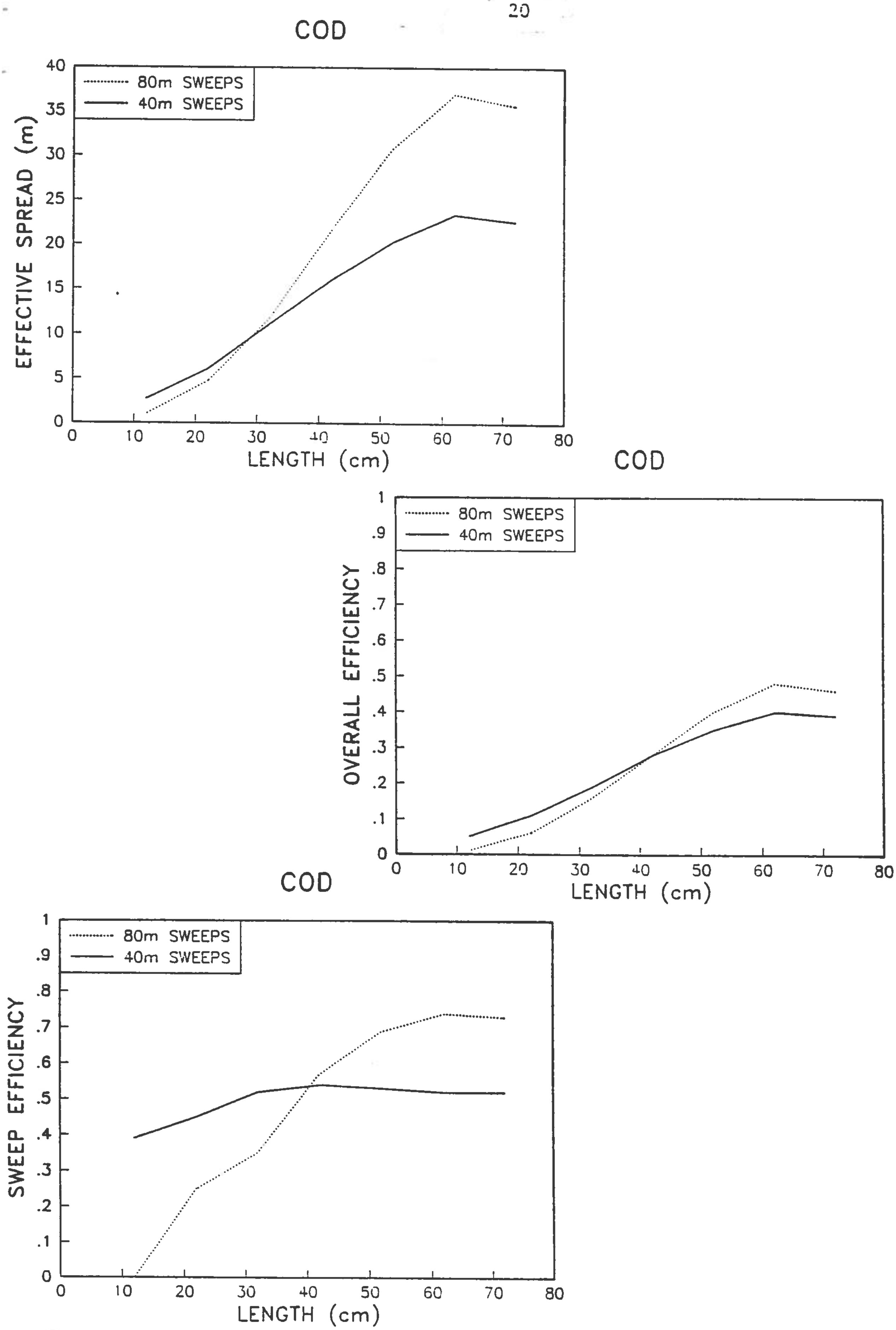
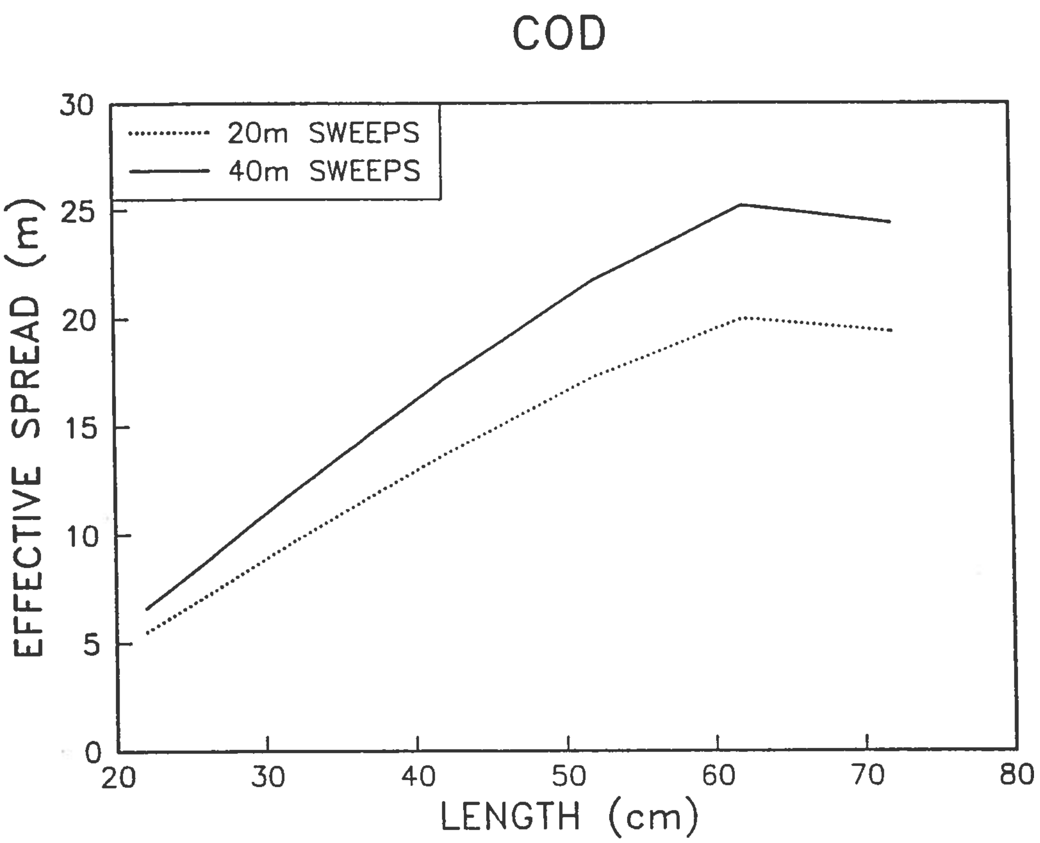


Figure 7. a) Effective spread.
b) Overall efficiency.
c) Sweep efficiency.
Both gears with bobbin groundrope.



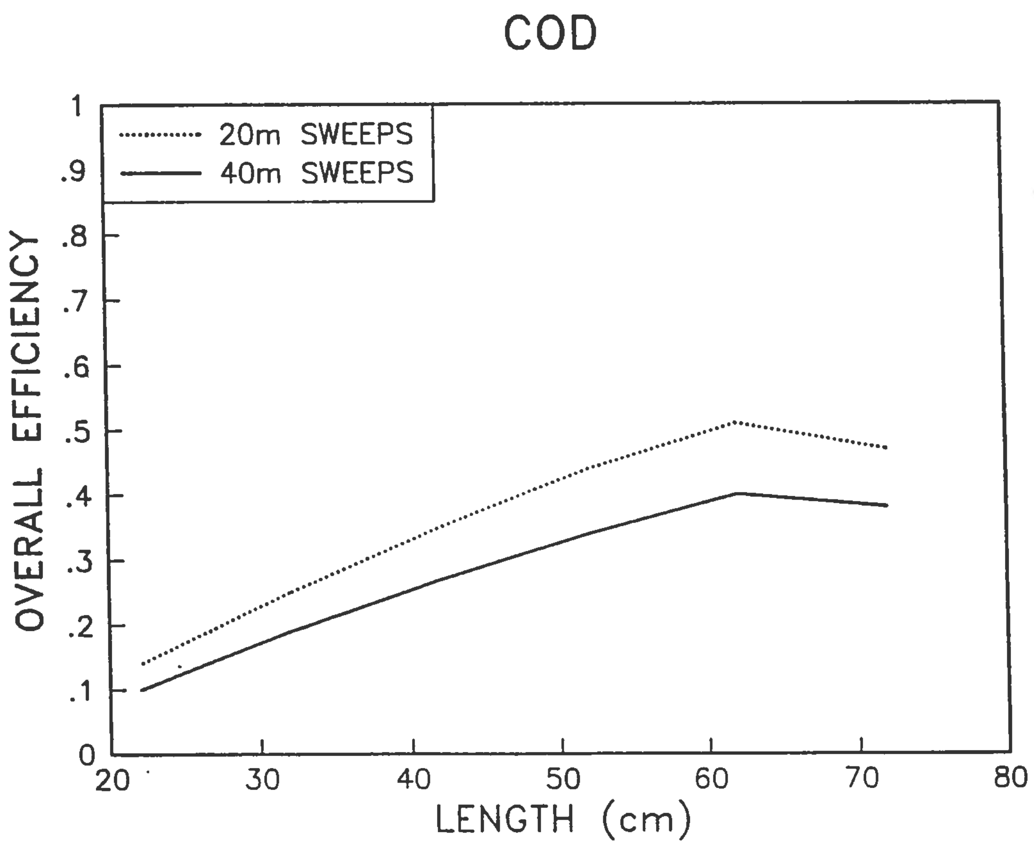
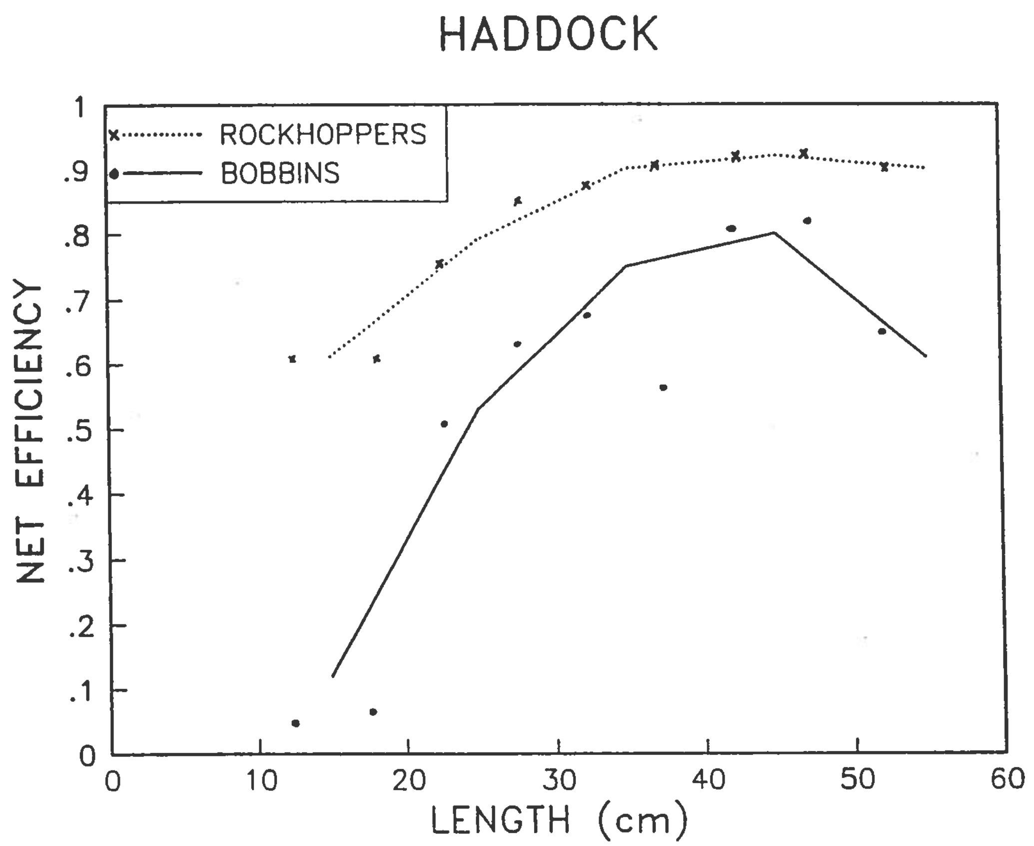


Figure 8. **Standard 40 m sweep rig compared with short 20 m sweep rig. a) Effective spread, b) overall efficiency, both gears with bobbin groundrope. The shorter sweep gear, though less effective (lower catchability), is more efficient.**



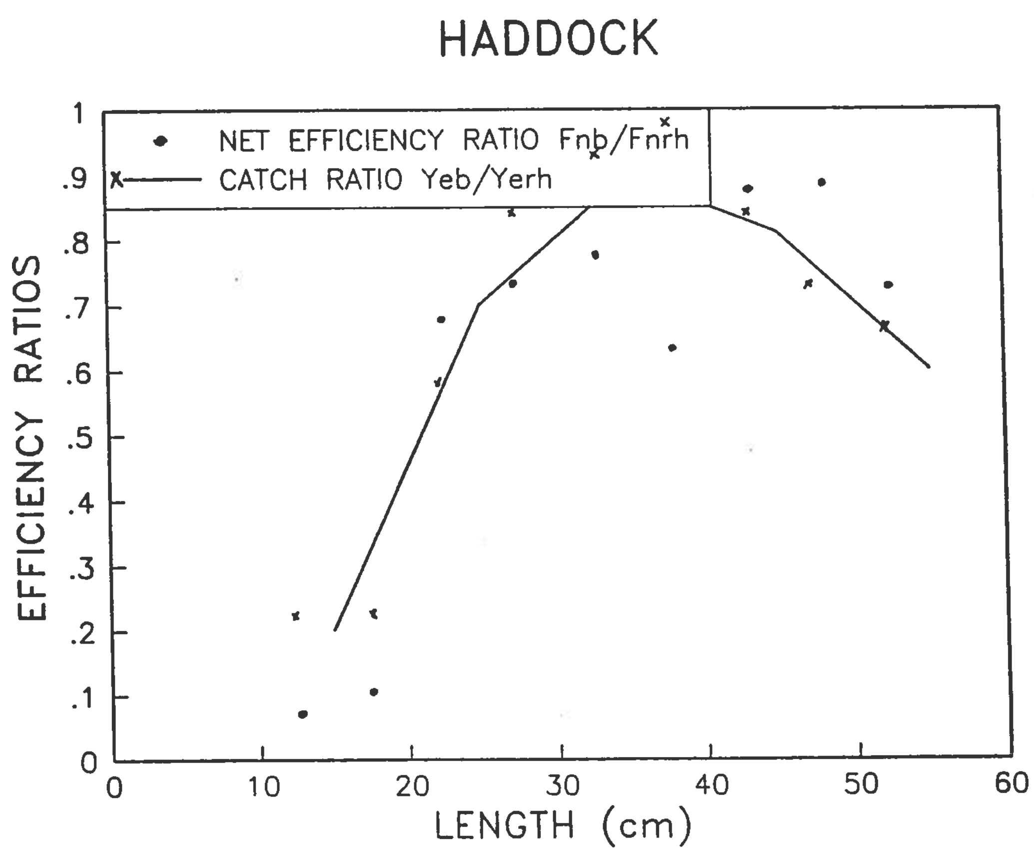


Figure 9. **Haddock comparisons with bobbins and rockhoppers, both with 40 m sweeps. a) Net efficiencies with plots derived from bag experiments, correction is made for those remaining in front of the groundrope on hauling, b) ratio of net efficiency, and also catch ratio agreeing fairly well with it.**

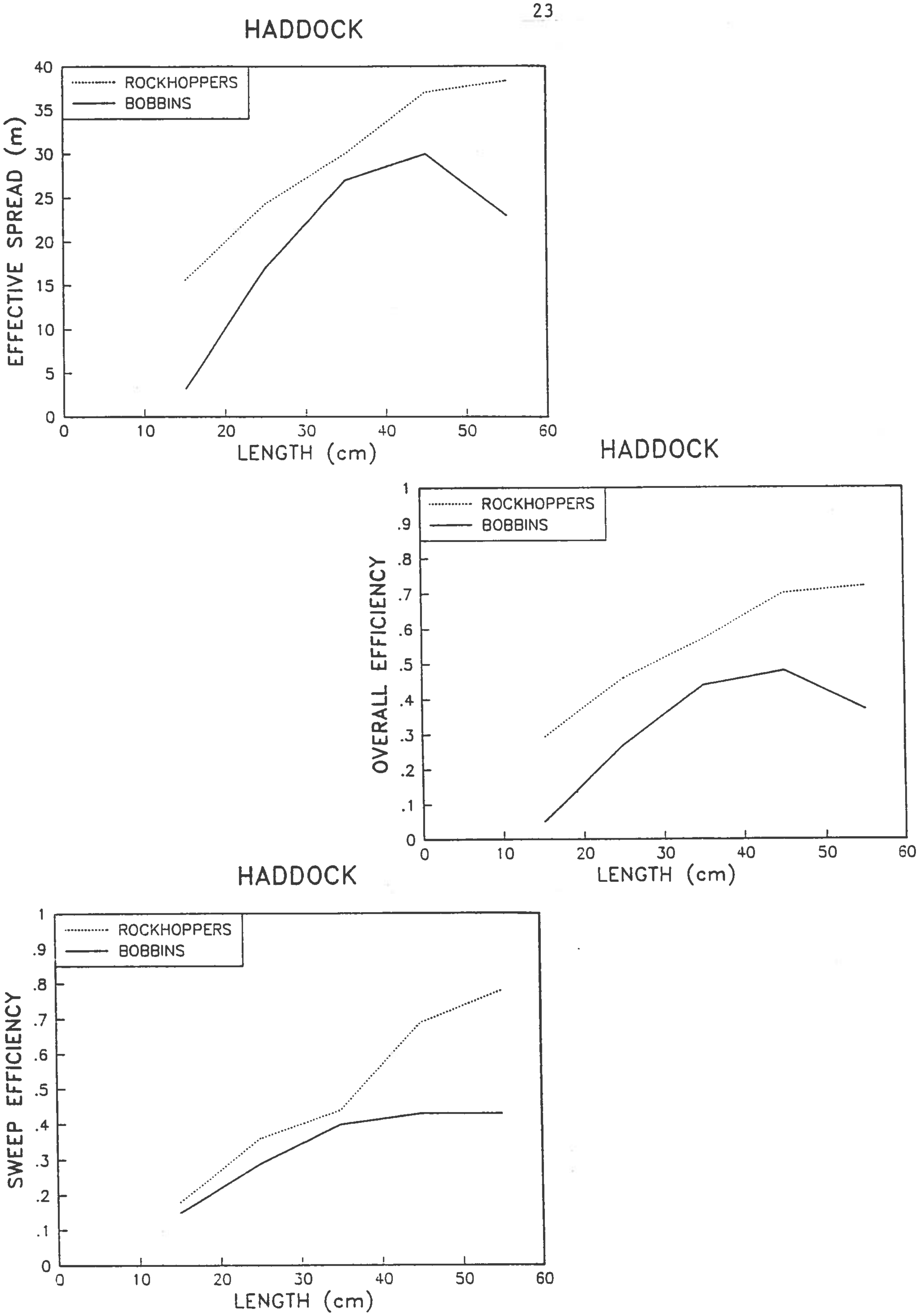


Figure 10. **a) Effective spread.**
b) Overall efficiency.
c) Sweep efficiency.
For haddock with bobbin and rockhopper gears, both with 40 m sweeps.

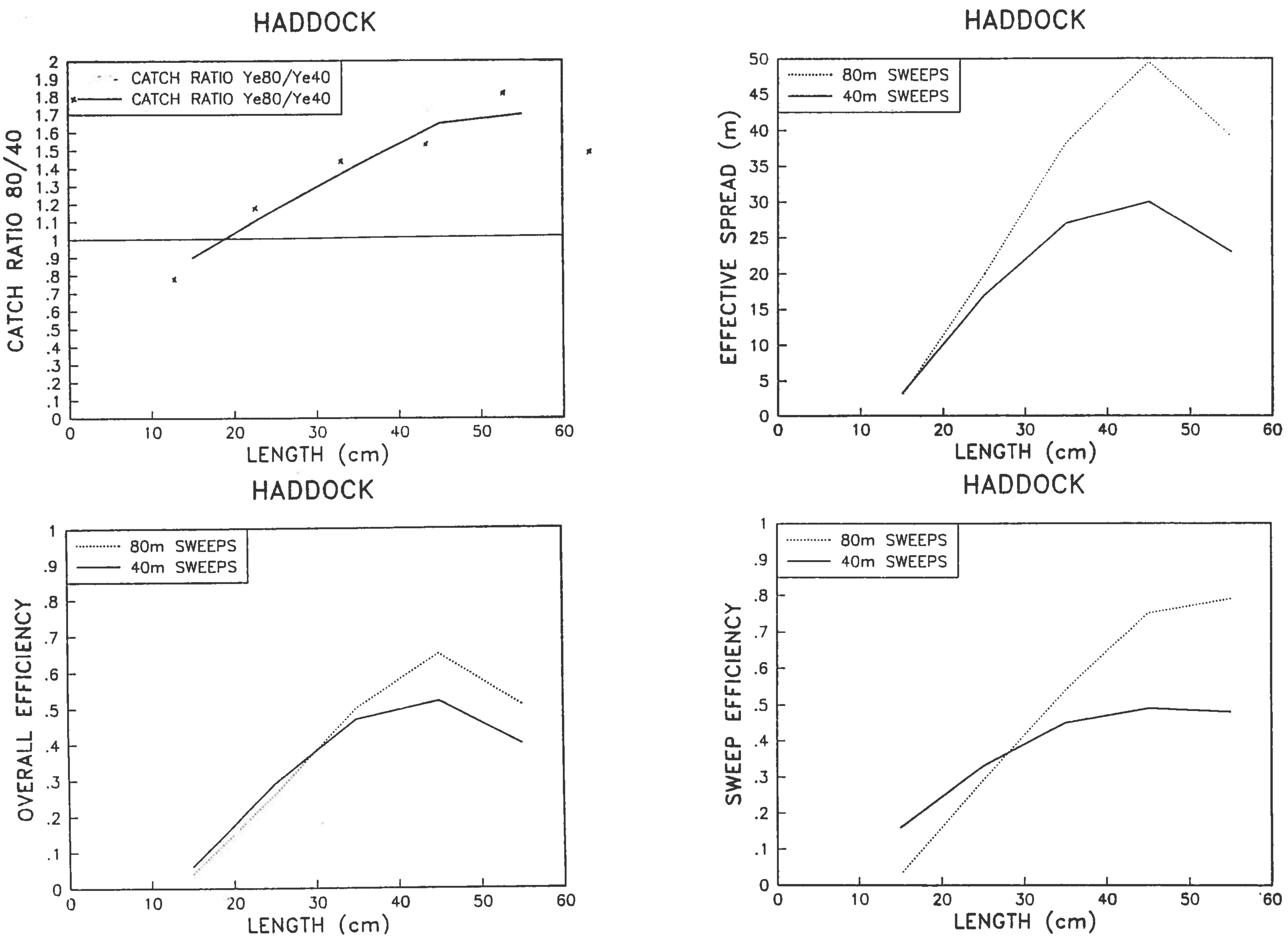


Figure 11. **Comparisons for haddock with 80 m and 40 m sweeps, both gears bobbin rigged. a) Catch ratio by 10 cm length groups and smoothing used, b) effective spreads, c) overall efficiencies, d) sweep efficiencies.**

Appendix 1

A POSSIBILITY OF ESTIMATING ESCAPES THROUGH THE MESHES IN THE FORWARD PARTS OF A TRAWL?

Estimating escapes through the big meshes in the forward parts of trawls has been elusive. Now that data on net efficiency are available from the bag experiments carried out by Engås and Godø (1989) with a small mesh sampling trawl (C 1800) and similar data are available from Walsh (1989) using an Engel 145 High Rise trawl with 180 mm and 150 mm size in the forward parts, we may be within sight of ways to tackle this problem.

Analysis

The data on net efficiency are taken from the two sources, are plotted out on Figure 1, smoothed into 10 cm groups, cod. As Walsh says in his discussion, he has not considered all forms of escape. A simple correction for fish left swimming in front of the net after a 1/2 hour tow (3240 m at 3 1/2 knots) is subtracted in Figure 1. This is derived from Figure 2, modified from Blaxter (1969). Net efficiency is simply reduced by the fraction (distance to exhaustion-/3240) for the bigger length groups. This has also been done for the C1800 trawl towed at 3 knots. The C1800 plots with bobbins and rockhoppers are entered on Figure 1 for comparison. Walsh fortunately has data for cod at the top end of the size range. The plot of the Canadian cod looks rather more like the plots obtained in the Barents Sea for haddock. The rise of the Canadian plots is steeper and to a higher level of net efficiency, higher even than the C1800 with rockhoppers.

As Walsh notes, there are likely to be escapes through the meshes of the E145 trawl which are not accounted for. A possible way to proceed is to consider the E145 trawl as it is, and also to consider the likely effect if it had been a small mesh trawl (like the C1800), and then to set in some ranging shots for escapes through the meshes and see what could happen.

Escapes through the meshes of the E145 seem unlikely beyond cod 60 cm, so it is only necessary to calculate up to the group 50-59 cm. Let the escapes through the meshes be called ME, and let the net efficiency of the 145 trawl as is be f_{n145}, and the hypothetical small mesh 145 trawl be f_{n145sm}, and as usual efficiency f_n = codend/(codend + escapes), f_{n145} = codend/(codend + bags + ME), f_{n145sm} = (codend + ME)/(codend + bags + ME).

Using the following data from Walsh, by 10 cm groups:

Group	10/19	20/29	30/39	40/49	50/59	60/69	70/79	50/59* smoo-thed
Codend	5	32	19	21	91*	71	24	81
Total	263	339	50	33	101*	79	27	100
f_n	0.02	0.09	0.38	0.64	0.9*	0.9	0.89	0.81

Put in some ranging shots for ME, start with 20, 40, 80, etc., and reconsider later:

Group 10/19	ME	f_{n145}=5/(263+ME)	f_{n145sm}=(5+ME)/(263+ME)
	0	0.02	0.02
	20	0.02	0.09
	29	0.017	0.12
	40	0.02	0.15
	80	0.01	0.24 too high
Group 20/29	**ME**	**f_{n145}=32/(339+ME)**	**f_{n145sm}=(32+ME)/(339+ME)**
	0	0.09	0.09
	40	0.08	0.19
	80	0.08	0.26
	96	0.07	0.29
	160	0.06	0.38 too high
	320	0.05	0.53
Group 30/39	**ME**	**f_{n145}=19/(50+ME)**	**f_{n145sm}=(19+ME)/(50+ME)**
	0	0.38	0.38
	5	0.35	0.44
	10	0.32	0.48
	20	0.27	0.48
	29	0.24	0.61
	40	0.21	0.66 too high

Group 40/49	ME	f_{n145}=21/(33+ME)	f_{n145sm}=(21+ME)/(33+ME)
	0	0.64	0.64
	5	0.55	0.68
	10	0.49	0.72
	13	0.46	0.74
	20	0.40	0.77 too high
	40	0.29	0.84
	80	0.19	0.89
Group 50/59	ME	f_{n145}=81/(100+ME)	f_{n145sm}=(81+ME)/(100+ME)
	0	0.81	0.81
	5	0.77	0.82
	10	0.74	0.83
	14	0.71	0.83
	20	0.68	0.84
	40	0.58	0.86
	80	0.45	0.89 too high

Group 60/69 considered as ME = 0

It will be seen that the trend of increasing ME tends to lower f_{n145} at the same time as it increases the hypothetical case of f_{n145sm}. Now for smallish cod, f_{n145sm} might be a little greater than f_{nb} (C1800 with bobbins). It is not, however, likely to be greater than f_{nrh} (C1800 with rockhoppers) for smallish cod. It can be expected that f_{n145} will be lower than f_{nb} (C1800) for small cod, because it is not a small mesh net. These constraints put a limit on the upper value of ME that would seem reasonable and so an interpolated value can be chosen. The plots of f_{n145} and f_{n145sm} (Fig. 3) have to be on either side of the simple plot (Fig. 1), and will merge with the simple plot for a fish length that will not go through the forward meshes.

For one thing, small fish will probably not seek escape through the belly meshes, for another it has not been found necessary to use small mesh sizes in the forward parts of industrial trawls used to catch small gadoids like *Trisopterus esmarki.*

The best that can be estimated as the actual net efficiency of the E145 net as is seems a credible enough shape and remarkably efficient for big fish. The net efficiency may now be considered in two parts, firstly escape at the groundrope, secondly escape through the meshes. For the second part, encounters are those that pass above the fishing line.

The efficiency in the netting part is thus:

codend/(ME + codend)

This is plotted in Figure 4 from the following:

Length (cm)	10/19	20/29	30/39	40/49	50/59	60/69	70/79	80+
Codend	5	32	19	21	91	71	24	81
ME	29	96	29	13	14	-	-	-
codend/(ME + codend)	0.15	0.25	0.40	0.62	0.87	1.0	1.0	1.0

It might be considered from Figure 4 that the mesh escapes have been pitched too high.

This method of estimating mesh escapes must as yet be rough because so far there is only data from 3 rigs to check against each other, C1800 bobbins, C1800 rockhoppers, and H145 bobbins. It does show, however, how one can progress with even relatively few measurements of real efficiency rather than merely relative indices. Some similar plots from the E145 with rockhoppers and with the C1800 and the E145 on the same fishing grounds at the same time would help greatly.

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Blaxter, J.H.S. 1969. Swimming speeds of fish. In: Ben Tuvia and W. Dickson (eds.): Proceedings of the FAO Conference on Fish Behaviour in relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October, 1967. *FAO Fish.Rep. 62*: 69-100.

Engås, A. and Godø, O.R. 1989. Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. *J.Con.int.Explor.Mer, 45*: 269-276.

Walsh, S.J. 1989. Escapement of fish under the footgear of a groundfish survey trawl. *ICES C.M. 1989*/B:21.

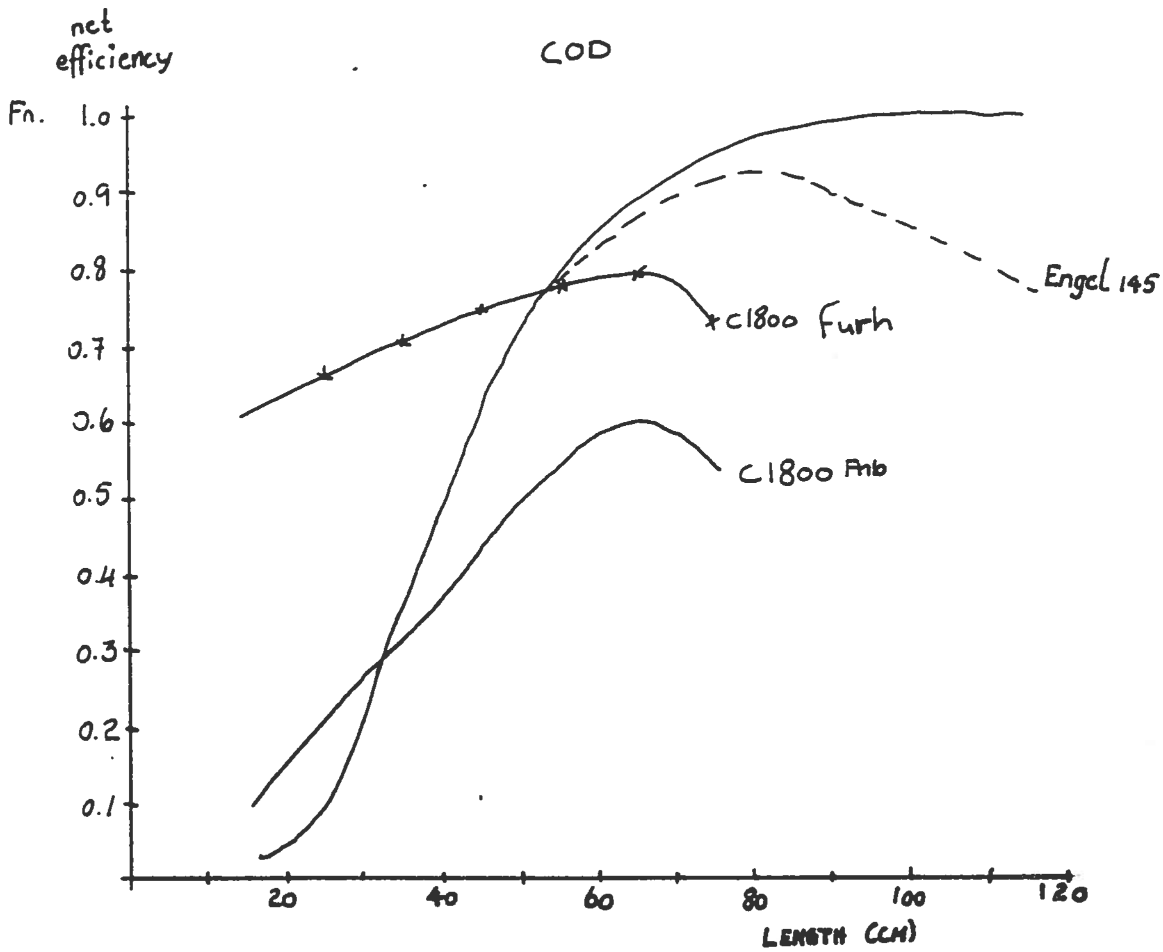

Figure 1. Net efficiencies of C1800 bobbins, C1800 rockhoppers and E145 compared. All are given a down turn for those big fish left swimming in front of the net after a half hour tow. No adjustment is made to the E145 for possible escapes through the forward parts of the net.

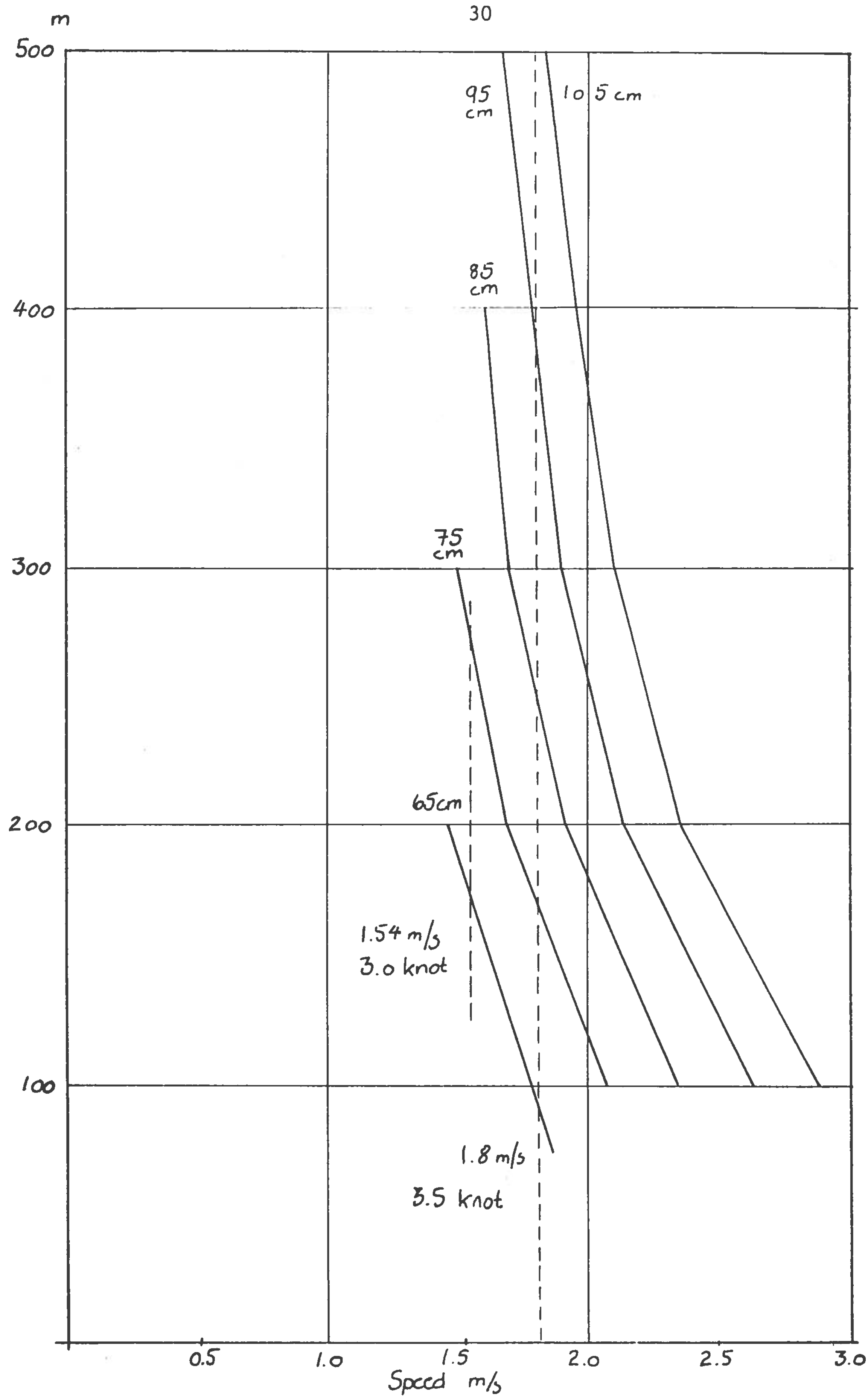

Figure 2. Cod, distance swum before exhaustion at a range of speeds, redrawn from Blaxter (1969).

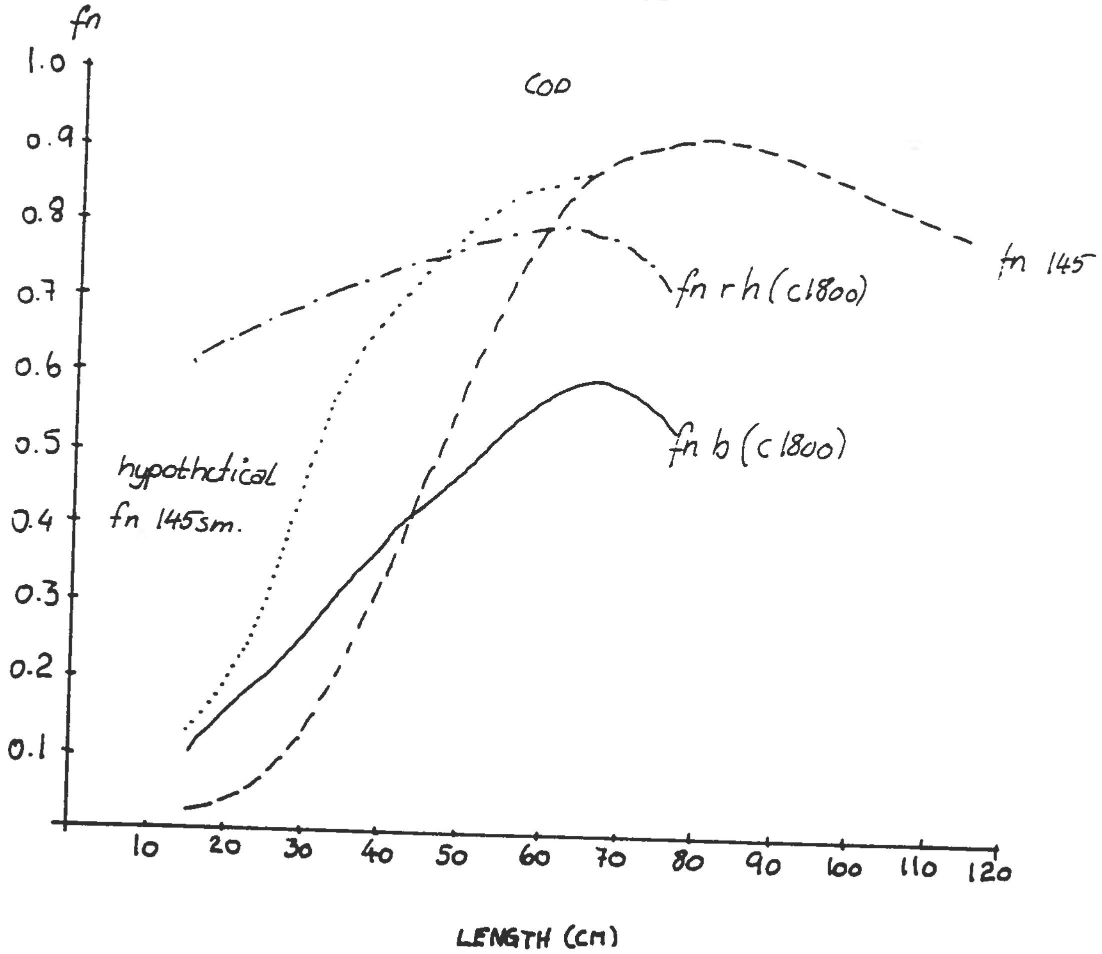

Figure 3. Net efficiencies, E145 net now readjusted for possible escapes through the meshes and the hypothetical case where these are precluded. The C1800 net with bobbins and rockhoppers are added as judgement constraints.

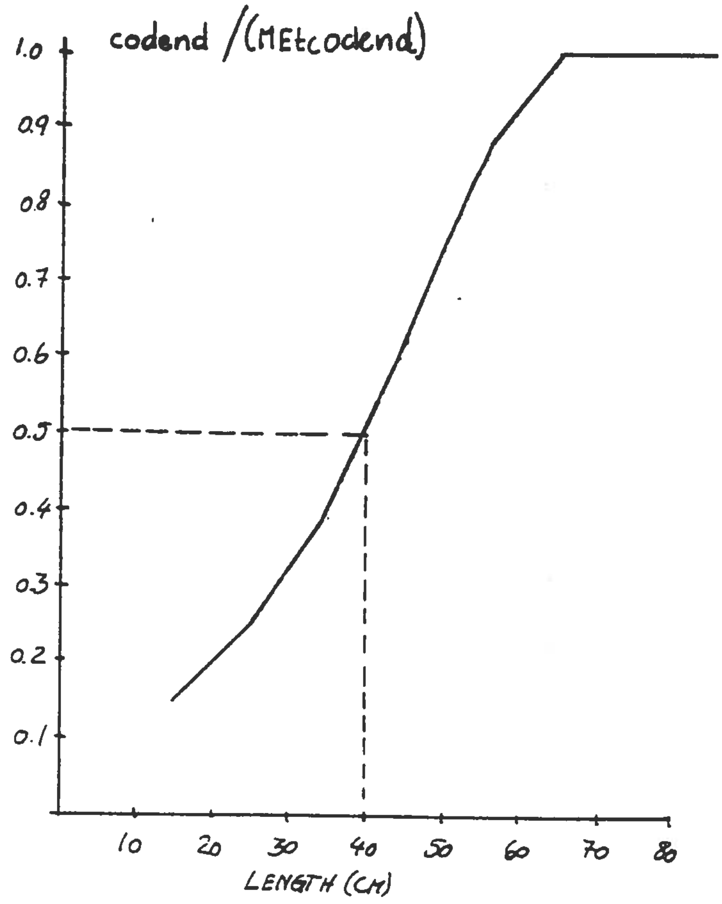

Figure 4. Estimate of net efficiency for those cod that pass over the fishing line of the E145 net. The estimate of mesh escapes may still be pitched rather high.

Appendix 2

COMPARATIVE EFFICIENCIES OF DIFFERENT SURVEY TRAWLS

It is interesting to compare the comparative efficiencies of different trawls. Not all the information from different sources is, however, directly comparable. The bag experiment from Engås and Godø (ibid.) and from Walsh (ibid.) deal with fish in different areas. The raw data from the bag experiments is manipulated to give estimates of net efficiency, but it requires more manipulation by including sweep and otterboard effect to arrive at gear efficiencies and effective spread. Other experiments like comparative fishing data from two trawls are comparing their catchabilities. Such an experiment is the comparison of the Norwegian C1800 trawl and the Russion 41.7/39.6 trawl, as used by "G.O. Sars" and "Menzelinsk" in February 1985. The numbers for the Russian trawl refer to headline length and stretched distance round the bag in metre. With headline heights of about 4 m and 6.5 m, respectively, it requires the assumption that the fish on encountering the gear are all within 4 m from bottom to be able to say that effective spreads are being compared. Even then one has to know the otterboard spreads in both cases to compare overall gear efficiencies plus farther manipulation to arrive at net efficiencies. Another experiment, Zaferman and Serchrov (1983) arrives at a measurement of overall efficiency by surveying the local abundance from a towed submersible and by trawling. In this case no manipulations are made because gear dimensions are uncertain, but seem likely to have been the same 41.7/39.6 trawl as used by "Menzelinsk".

To help understanding of the comparisons the following operating dimensions are relevant:

Trawl	Y_B m	Y_N m	Sweeps etc. m	Spread ratio	Sweep angle	Otter-boards m^2	
C1800	62	19.5	50	0.67	25°	6.4-7.5	Various
41.7/39.6	70*	25	95	0.60	13.7°	5.5	Probably Matrosov
E145	41*	15.2	62	0.52	12°	3.8	Oval polyvalent

The * indicates an estimated value from the spread ratio (headline spread/headline length). Matrosov otterboards are flat oval and slotted. Mean sweep angles are derived from otterboard spread, net spread, and the length of sweeps, bridles, and backstrops (door to wingend). The case of the 40 m sweeps, C1800 net bobbin gear has already been discussed.

Cod comparisons

For cod the assumption of fish being within headline height of both the C1800 and the 41.7/39.6 net is probably reasonably safe. Raw data from the comparison is given at the left hand side of Table 1, and the manipulation of it follows. Since catch ratios are above and below 1:1, the best way to smooth the data seems to take logs of the ratios, smooth these, and convert back again. Smoothing is done by eye. Having already estimated the effective spread for the C1800 gear, the effective spread of the Russian net follows as $Y_{e41.7}$. Overall efficiency f follows as $Y_e/70$. Sweep efficiency is taken as for the 80 m sweep case of the C1800 gear in the first instance (Fig. 7b), and the net efficiency for the Russian net follows as f_n.

If sweep efficiencies are set instead half way between the 40 m and 80 m sweep case, as 0.3, 0.42, 0.52, 0.62, 0.63, 0.63, then $f_{n41.7}$ comes as 0.03, 0.08, 0.17, 0.27, 0.37, 0.53, 0.61. Thus it seems that the setting of sweep efficiency for the 41.7/39.6 net is not particularly critical for the derivation of its net efficiency from the effective spread.

In the case of the E145 net, there are no comparative fishing data. There are, however, derived values of net efficiency that can be used and with some reasonable assumptions of sweep efficiency, then effective spread and overall efficiency values can be derived. The values of f_n used are those as per Appendix 1, Figure 3. Values of sweep efficiency are set half way between the 40 m and 80 m sweep case from Figure 7b, as would seem appropriate for sweeps 62 m long.

Plots of effective spreads and efficiencies are given in Figures 1, 2, and 3, taken from Tables 1 and 2. The overall efficiency as derived from the submarine counting excercise is also plotted for comparison.

Haddock comparison

For direct comparison there are only the data acquired from "G.O. Sars" and "Menzelinsk". Here the difference in the headline heights of the two trawls used by the two ships may be more important. What is really being compared in comparative fishing (towing at the same speed) is $Y_{e(1)} \cdot F_{V3(1)} \cdot F_{H3(1)}/Y_{e(2)} \cdot F_{V3(2)} \cdot F_{H3(2)}$. The horizontal availability factors are too uncertain to attempt to compare, but for the vertical availability factor $F_{V3(1\ GOS)} \leq F_{V3(2\ Menz)}$. The values of effective spread and overall efficiencies derived for the 41.7/39.6 gear are thus to be considered as the maximums likely.

The procedure is the same as for cod. Effective spreads of the C1800 net with bobbins and 40 m sweeps are taken as before. The sweep efficiency of the 41.7/39.6 m gear is taken as for haddock with 80 m sweeps. The outcome is as in Table 3. Plots of the effective spreads and efficiencies are given in Figures 4, 5 and 6. Onto Figure 5 are also plotted the reciprocals of what Campana (1987) calls survey multiplication factors S.M.F. taken from area 4X off Nova Scotia.

Discussion

One thing all the plots of effective spread, overall efficiency and net efficiency have in common both for cod and haddock is their very low level at the bottom end of the size range compared with the top end. It must be clear that to arrive at anything like a true length/frequency distribution, some kind of raising factor or S.M.F. is required. This is apparent from both sides of the Atlantic and by methods as diverse as the one developed here, on to the use of mini submarine to obtain alternative estimates of abundance by size group and even to the comparison of trawl survey data with sequential population analysis (SPA) estimates.

On the technical side there is something unsatisfactory about a survey bobbin trawl where it seems that the herding into the path of the net is often better for small fish than from there into the codend. Two sources of loss have to be considered here, below the fishing line and through the meshes. The former may be improved by a better designed groundrope, the latter substantially eliminated by use of smaller mesh sizes. In addition to the problems of gear redesign, there is the problem of measuring the improvement achieved. Both these problems require adequate engineering calibration of gear dimensional performance.

The lack of good gear dimensional calibration must reduce the accuracy and worth of making the kind of gear efficiency analysis attempted in this appendix. Repeated comparison could not be expected to yield exactly repeatable results in any case due to changes in length composition available, changes in vertical distribution, and to changes in other conditions under which comparisons are conducted, we cannot control these, only choose conditions as best we can, but good gear calibration is something that can and ought to be done.

While there are for some of the gears rather weak indications of a downturn in effective spread and efficiency for the biggest of fish, and this is at least in part theoretically induced, the dramatic downturn given from the towed submersible, experiments is surprising in that any theoretical justification for such a drastic downturn is difficult to envisage.

There appears to be substantial differences between survey gears, those based on commercial designs for cod and haddock, being more successful for bigger fish (to varying degrees), and rather less successful than the C1800 shrimp trawl design for smaller fisk. The E145 seems to be so much better than the C1800 for cod above 45 cm (net efficiency), that it would be interesting to see comparative fishing results between the two gears on the same cod stock, and also to find the effect of improving the groundrope design of the E145.

The reciprocal of S.M.T. is plotted onto the graph of overall gear efficiency of haddock (Fig. 5), as being the most appropriate comparison, but I/SMF and f are not exactly the same thing. Several pre-conditions would be required for that:

- the estimate of f has to be correct,
- the estimate of sequential population analysis has to be correct,
- F_{V3} and F_{H3} have to be unity. All fish in the water column have to be available to the trawl, and the passage of the ship makes no horizontal re-distribution of the fish.

$$\textit{Catchability or effectiveness} \ / \ Y_b \cdot V = F_{V3} \cdot F_{H3} \cdot f$$

and by definition:

$$\textit{Effectiveness} \ / \ Y_b \cdot V = 1 \ / \ SMF$$

That is for any length group, 1/SMF equals the area that is effectively swept clean of fish (through the whole water column) as a proportion of the total area swept in that time. Determining Y_b and V are matters of gear technology and instrumentation; determining F_{V3} and the preceding steps F_{V1} and F_{V2} must largely be done by hydroacoustics; determining F_{H3} is for demersal fish firstly a question of whether it is a problem, and then, if so, how to solve it.

Riddle analogy

Fish are not inert like stones, nevertheless, thinking of trawl gear as a sequence of riddles may be helpful. Consider the encounters between otterboards and up to headline height, there are: the otterboard riddle, the sweep riddle, the groundrope riddle, the net riddle, and the codend riddle. At each stage there is selection and escape. For survey purposes escape is precluded at the codend riddle, and it may be advisable to preclude it at the net riddle also. Looking only at codend catches can tell very little about the amount and size composition of what was put into the first riddling stage. The bag experiments were a crucial step, especially when used with a survey net of rather small mesh size. For fish the first two riddle stages are interactive, largely dependent on gear dimensions and visibility, the same applies to the sweep and net stages, and the same within the net stage if the meshes are graded.

Day and night

There is hardly enough data yet to differentiate day and night effects, but it is beginning to come. By using rigs with doors off and on bottom, Dickson and Engås (1989) were able to show that for cod; there is distinctly more herding by day; there is less herding of small cod than bigger ones, and a flattening off of herding effect above 40 cm both day and night; and there was very little or no herding of small cod by night. Haddock show the same general trend, but the effects were less pronounced. From the data of Walsh (1989), small day and night differences in main catch/(bag catch + main catch) by cod length group appear, but could hardly be significant differences.

A final caution

None of the foregoing estimates are meant to be treated as carved in stone. They are simply the best estimate the author can currently make from the data available.

Next steps

More insight into day and night differences in otterboard effect, sweep and net efficiences, will be an important step. Vertical availability is another crucial factor for study. If one can then go on to consider these in terms of light level, range of visibility to important gear features, plus considering bottom currents relative to direction of tow and swimming speed, plus considering sand particle size, sand cloud spreading dimensions, and settling rate under the effect of the bottom current, then one can consider fitting these together into a trawl capture simulation model. This last must be a long term objective.

The more immediate tasks may be itemized as:

- Try to differentiate night and day differences in gear efficiency,
- More study of vertical availability,
- Use of raising factors to find if approximately the same length distributions can be derived from different survey gears in the same survey,
- Adequate operating dimensional information on all survey gears which are directly or indirectly concerned.

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Zaferman, M.L. and L.I. Serebrov, 1983. On methods of instrumental assessment of bottom and near bottom fish stocks in the Barents and Norwegian seas. *Proceedings of the Soviet-Norwegian Symposium on cod.* (Mimeo)

Table 1. Cod, estimate of effective spread and efficiencies of the 41.7/39.6 m trawl, starting from comparative fishing with the C1800 trawl.

	G.O.S.	Menz.	Y_{e1800}/-$Y_{e41.7}$	RBI	A	C	$Y_{e41.7}$	f	f_s	f_n
< 24	2686	359	5.75	5.5	34.5	59.5	1.0	0.01	0.2	0.03
25/34	674	298	2.88	6.5	33.5	58.5	3.5	0.05	0.33	0.09
35/44	507	269	1.88	7.5	32.5	57.5	8.0	0.11	0.53	0.17
45/54	600	417	1.45	8.5	31.5	56.5	13.4	0.19	0.66	0.25
55/64	87	71	1.20	9.5	30.5	55.5	19.2	0.27	0.71	0.35
65/74	33	51	0.83	10.5	29.5	54.5	27.7	0.40	0.71	0.51
75+	30	50	0.63	11.5	28.5	53.5	31.7	0.45	0.71	0.58

$A = Y_b - Y_n - R_{bo} - R_{bi} = 70 - 25 - 5 - R_{bi} = 40 - R_{bi}$

$B = Y_b - Y_n = 70 - 5 = 65$

$C = Y_b - R_{bo} - R_{bi} = 70 - 5 - R_{bi} = 65 - R_{bi}$

$Y_e = f_n(Y_n + f_s A)B/C$ hence f_n

Table 2. Cod, estimate of effective spread and efficiencies of the E145 trawl, starting from derived values of net efficiency.

	R_{bi}	A	C	f_n	f_s	Y_e	f
15/24	5.5	15.3	30.5	0.03	0.3	0.7	0.02
25/34	6.5	14.3	29.5	0.12	0.42	3.1	0.08
35/44	7.5	13.3	28.5	0.32	0.52	8.9	0.22
45/54	8.5	12.3	27.5	0.55	0.60	16.2	0.40
55/64	9.5	11.3	26.5	0.76	0.62	22.9	0.56
65/74	10.5	10.3	25.5	0.88	0.63	26.9	0.66
75/84	11.5	9.3	24.5	0.91	0.63	28.1	0.69
85/94	12.0	8.8	24.0	0.90	0.63	28.0	0.68
95/104	12.5	8.3	23.5	0.86	0.63	26.9	0.66
105+	13.0	7.8	23.0	0.81	0.63	25.5	0.62

$A = Y_b - Y_n - R_{bo} - R_{bi} = 41 - 15.2 - 5 - R_{bi} = 20.8 - R_{bi}$
$B = Y_b - R_{bo} = 41 - 5 = 36$
$C = Y_b - R_{bo} - R_{bi} = 41 - 5 - R_{bi} = 36 - R_{bi}$
$Y_e = f_n(Y_n + f_s A)B/C$

Table 3. Haddock, estimate of effective spread and efficiencies of the 41.7/39.6 m trawl, starting from comparative fishing with the C1800 trawl.

	G.O.S	Menz.	$Y_\bullet$1800/ $Y_\bullet$41.7	R_{bi} m	A	C	$Y_\bullet$41.7 m	f	f_s	f_n
10/19	1199	237	5.06	5	35	60	0.6	0.01	0.18	0.02
20/29	9205	3909	2.35	6	34	59	7.2	0.10	0.36	0.18
30/39	1429	1316	1.26	7	33	58	21.4	0.31	0.44	0.48
40/49	941	995	0.95	8	32	57	31.6	0.45	0.69	0.59
50+	21	28	0.75	9	31	56	30.7	0.44	0.78	0.54

$A = 40 - R_{bi}$
$B = 65$
$C = 65 - R_{bi}$
$Y_\bullet = f_n(Y_n + f_s A)B/C$ hence f_n

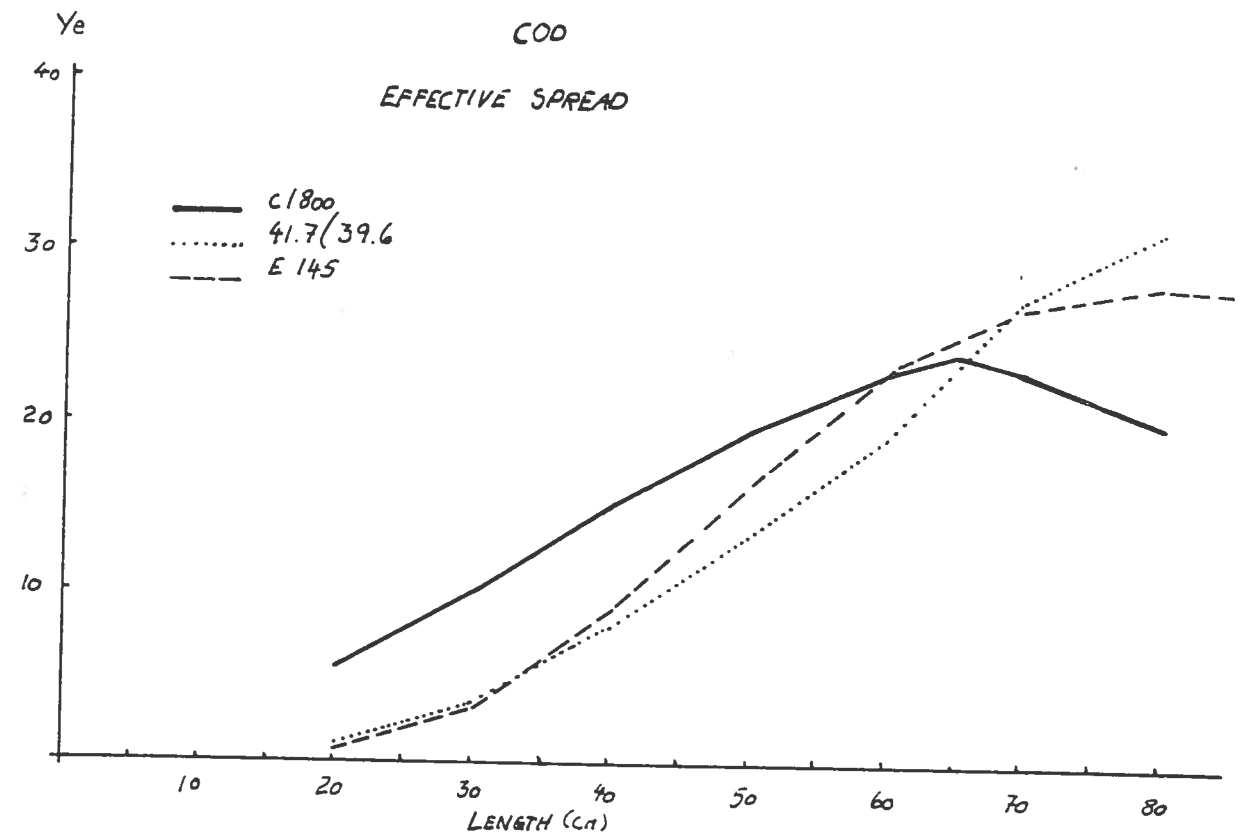

Figure 1. Effective spread of 3 different survey trawls used in demersal fish survey.

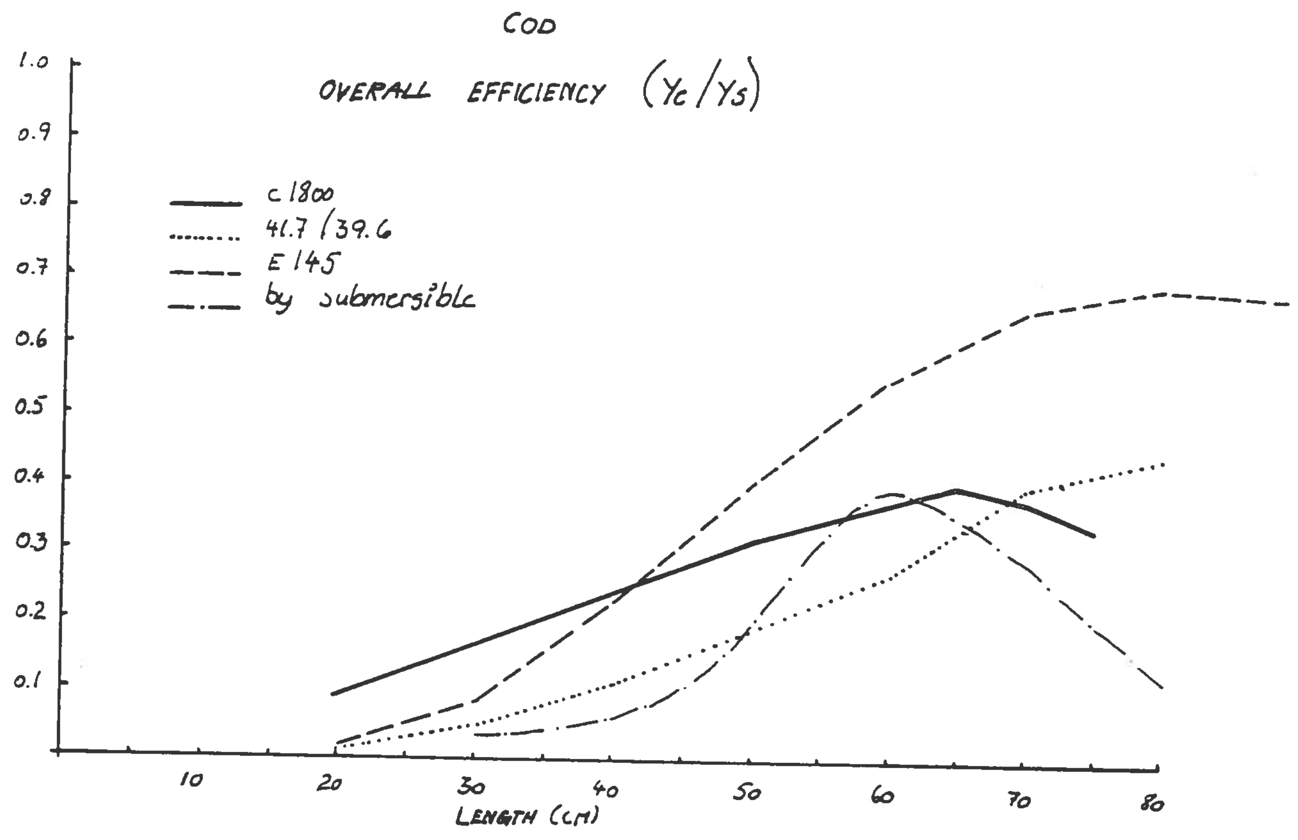

Figure 2. Overall efficiency of the same 3 survey trawls, and also of a trawl (probably 41.7/39.6), where the abundance was estimated from a towed submersible.

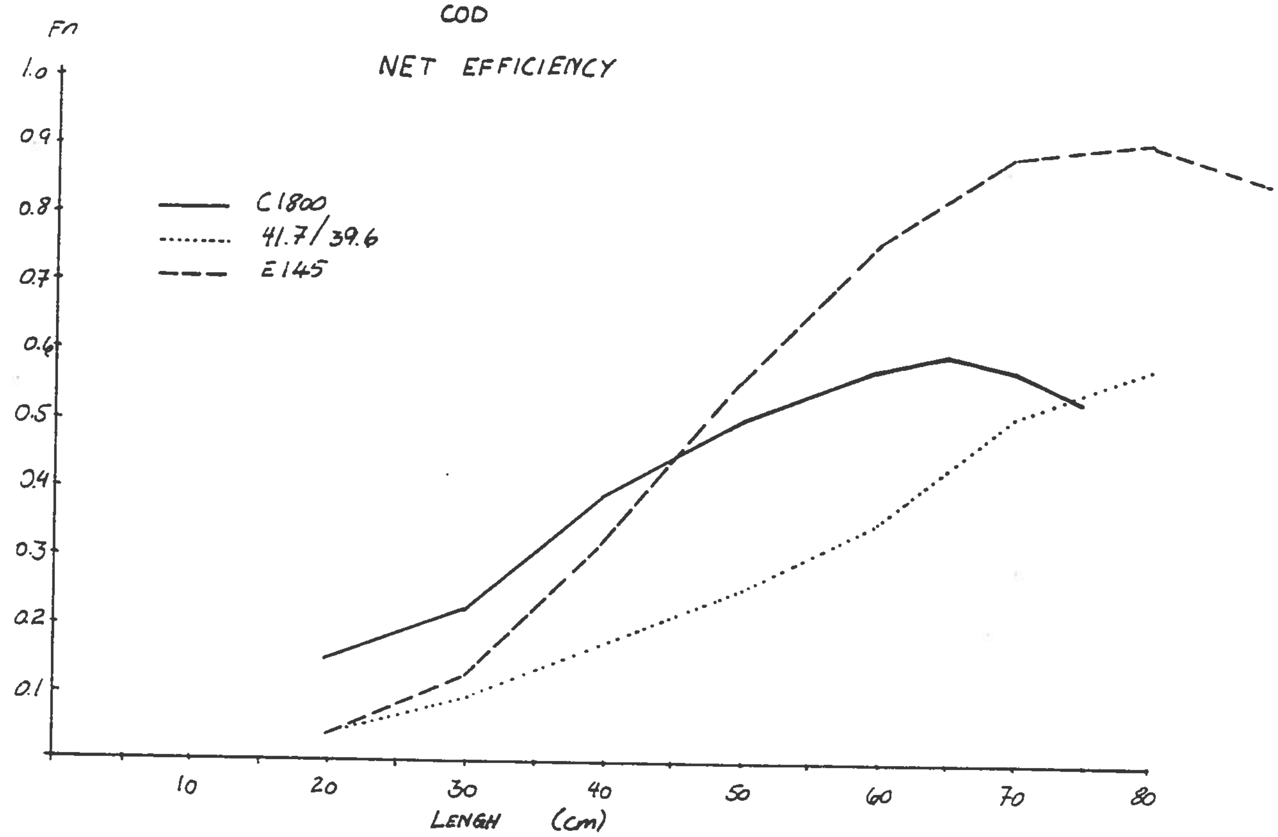

Figure 3. Net efficiency for the same 3 trawls.

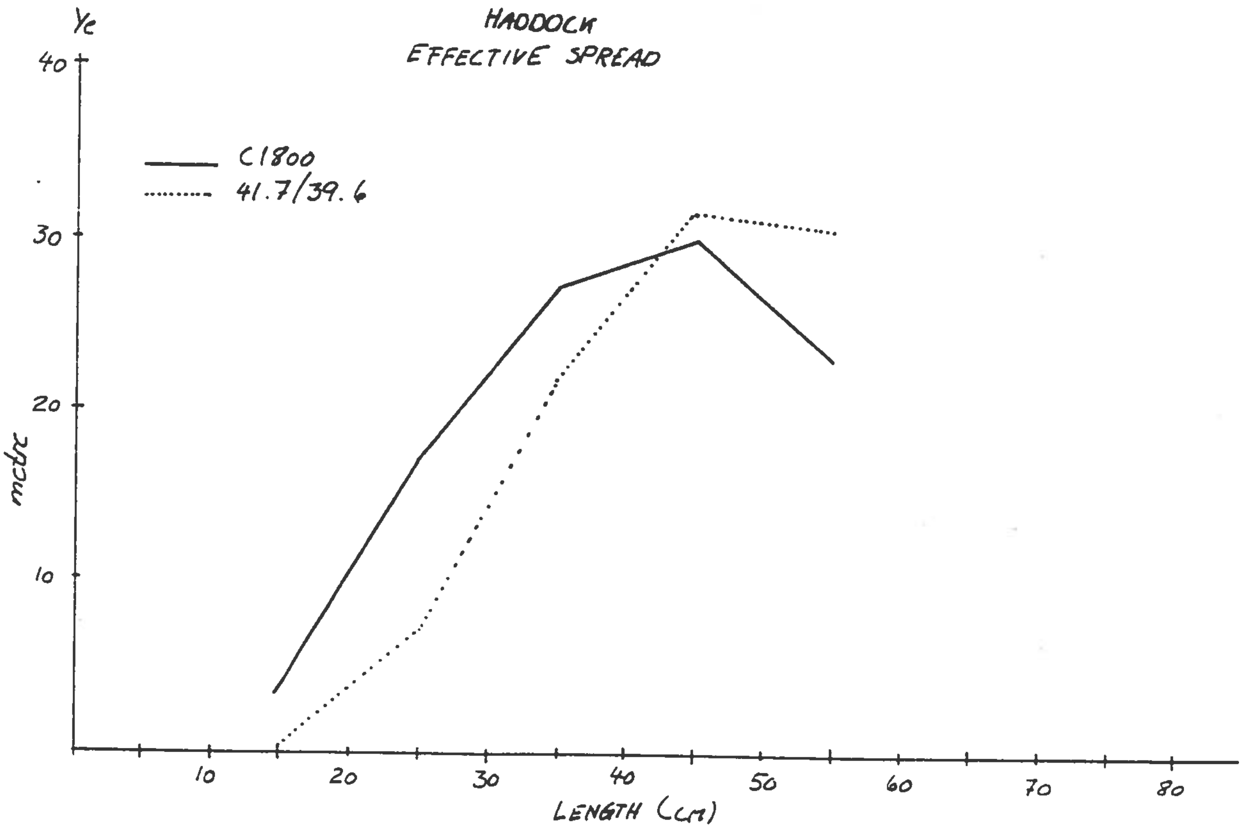

Figure 4. Effective spread of 2 survey trawls used for haddock.

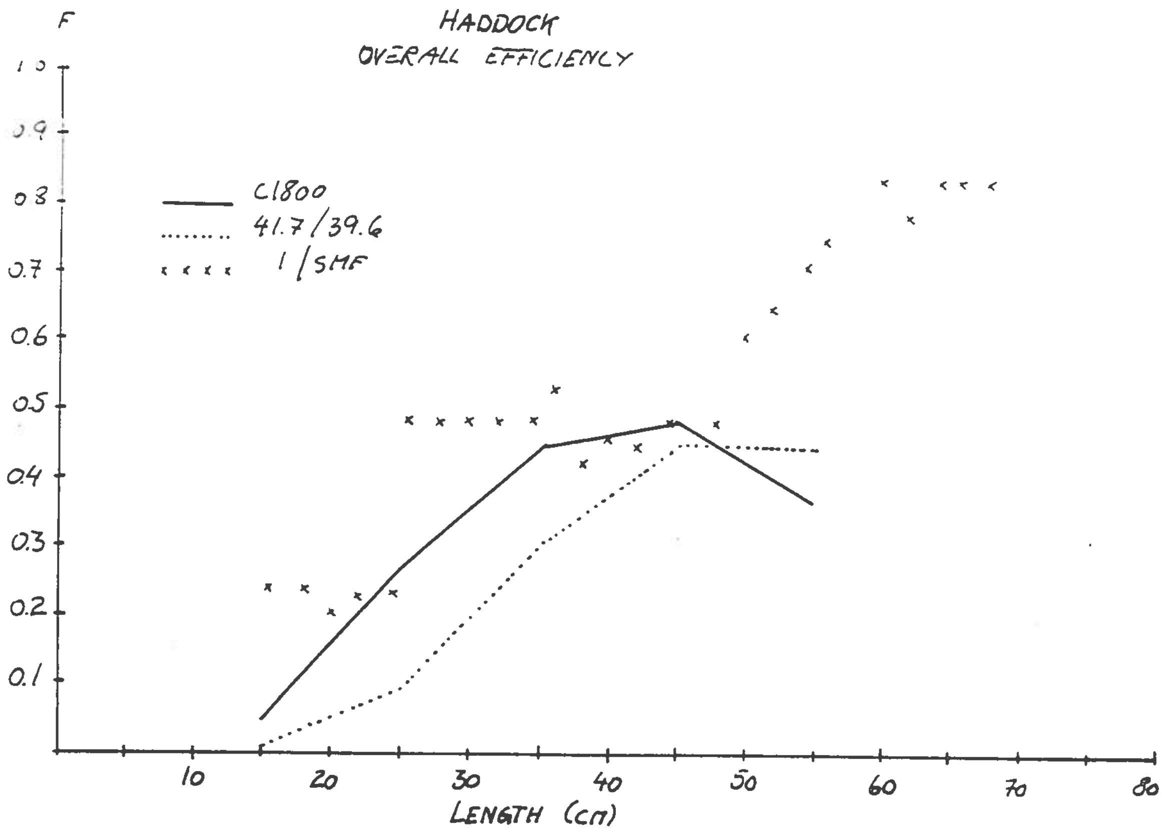

Figure 5. Overall efficiency of the same 2 survey trawls used for haddock plus a plot of 1/SMF (reciprocal of survey, mulitplication factor), which is not exactly the same thing, but see text.

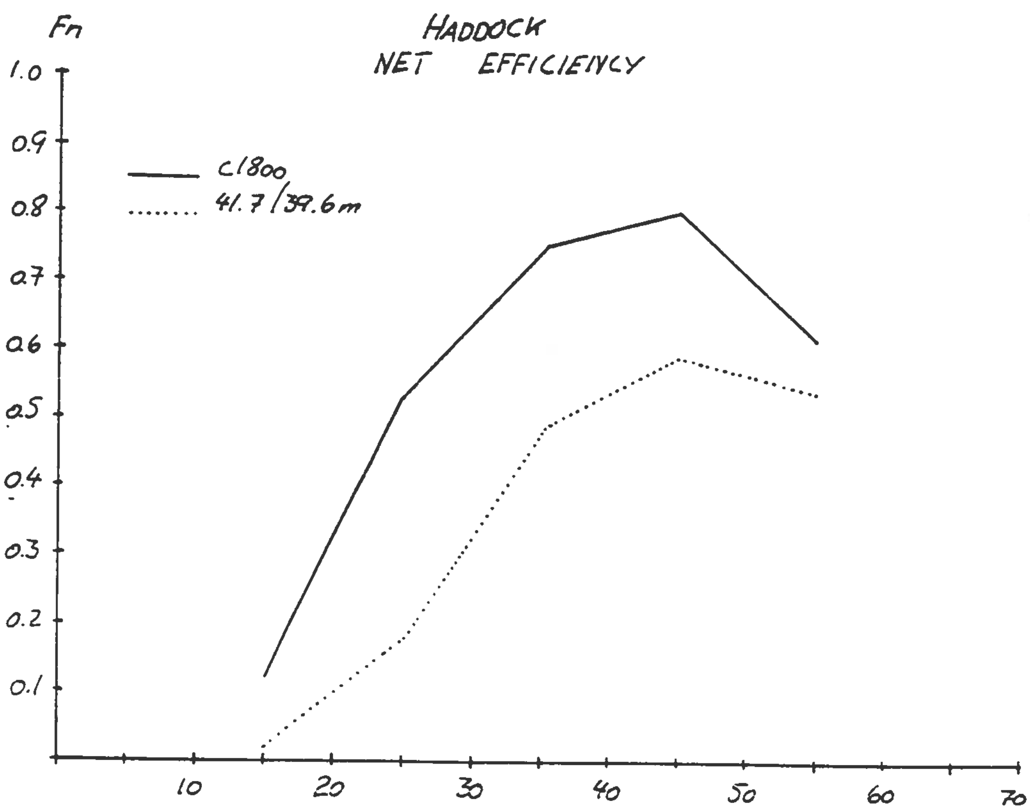

Figure 6. Net efficiency of the 2 survey trawls for haddock.